THE UNIVERSITY OF ALBERTA

A COMPUTER-BASED AGGREGATE PRODUCTION PLANNING SYSTEM FOR SMALL MANUFACTURING INDUSTRIES

by

© TEJINDER SINGH

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ABSTRACT

An aggregate production planning system has been designed and developed for use in a variety of small manufacturing industries. The central analytical component of this system is formulated within the framework of the Search Decision Rule for solving the operations planning problem. The production/cost models used in the system are designed to reflect the typical operating environment encountered in most manufacturing industries. The system performance was assessed using a hypothetical planning problem. Further empirical testing is recommended in order to assess the practical capabilities of the system.

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CHAPTER 1

INTRODUCTION

1.1 Purpose

This research is directed at developing an aggregate production planning system as part of a total corporate planning model that can be used by small manufacturers. It is hoped that this research will offer the small manufacturer a planning model that can improve his competitive position in todays business world. The production planning model developed herein uses a search routine that interacts with the objective function to generate near optimum values for each period (month) for (1) direct work force levels, (2) indirect work force levels and (3) production volumes by product line. With values for these three parameters reasonably complete cost data for the production planning purposes is generated and output by the system.

1.2 Background Information

Considerable work has been done with respect to the development of aggregate planning models. These models fall into the general classification of the Linear Decision Rule (LDR), linear programming methods, heuristic programming models and computer search methods in the form of the Search Decision Rule (SDR).

The development of the Linear Decision Rule by Holt, Modigliani, Muth and Simon [20,21,22] in 1955 represented a major step in the development of a planning model that appeared to have some real value in a practical sense. The model was tested in a paint factory using actual past data over a period of six years. The analyses indicated a minimum cost saving of 8.5 percent by the use of the LDR over actual management performance. The LDR model formulation involves the development of a quadratic cost function for the company in question. The cost function consists of such costs as the regular payroll, hiring, layoff, overtime, inventory holding, backordering and machine setup costs. Then, using this quadratic cost function two linear decision rules are derived for computing work force levels and production rate for the upcoming period based on the forecasts of aggregate sales over some planning horizon. These two linear decision rules are optimum for the model. The LDR was later extended to a multi-item production situation by Bergstrom and Smith [1] who refer to it as the "Multi-Item Decision Rule (MDR)". The Linear Decision Rule has been used as a comparative test model by many other individuals over the past twenty years.

Among the linear programming models work by Bowman [3] and by McGarrah [29, pp. 124-127] are worthy of mention. Bowman proposed the distribution model of linear programming as a mode for aggregate production planning in 1956. The model was built around the objective of allocating units of

productive capacity such that the total production and storage costs were minimized and sales demand was met within the constraints of available capacity. McGarrah proposed a simplex model for aggregate production planning covering such aspects as production change costs, inventory holding and backordering costs. The major disadvantage with these models is that they are based on a planning horizon of only one period. The simplex models which have larger horizon times have also been developed by McGarrah [29, pp. 127-129] and Hanssmann and Hess [18]. The Hanssman-Hess model determines the work force level and the production rate as independent variables with the regular payroll, hiring, layoff, overtime, inventory, and backordering costs as dependent variables. The model allows for a presetting of the planning horizon time.

The linear programming methods and the Linear Decision Rule produce mathematically optimum decisions provided the basic cost structure of the model accurately represents the dynamic operating characteristics of the firm. These models, in fact, are unable to realistically duplicate the actual operating conditions because of their very basic requirements of continuities and specific forms for the cost functions.

Under the heuristic programming methods, there are two rather different proposals for handling the aggregate production planning problems. The first, Bowman's management coefficients model [4], uses past average managerial

performance to derive coefficients for decision rules. Bowman hypothesizes that management's decision-making criteria is in no way different from that used in analytical models except that managerial behaviour tends to be highly variable about optimality rather than being off-centre. Thus, he presumes that overall managerial decisions can be improved considerably over a period of time through consistent use of decision rules. The industrial application of this technique is limited due to the fact that the manager may not be fully aware of (the components, the exact nature, and the dynamic characteristics) the firm's actual cost structure and the lack of this knowledge will lead to the biasing of decisions. The second heuristic model is called Parametric Production Planning (PPP) and was developed by Jones [24]. The PPP model is based on a simulation approach built around the postulated existence of two specific linear feedback rules with coefficient values obtained from a four dimensional search of possible parameter values derived from a linear and/or non-linear model of the firm's cost structure. This model does not place any limitations on the mathematical form of the cost functions, as there are with the Linear Decision Rule and linear programming. In the paint factory application the PPP model yielded decisions which were almost the same as those given by the optimum Linear Decision Rule.

Finally, the Search Decision Rule (SDR), developed by Taubert [42,43], utilizes a modified Hooke-Jeeves computer

search method. Under the Search Decision Rule, the planning problem is first defined as a multi-stage decision system and then solved for a global optimum by using a computer search technique as a heuristic optimum-seeking method. The search method used in SDR, the "Pattern Search", was developed by Hooke and Jeeves [23] and later modified by Weisman, Wood, and Rivlin [50], and by Taubert [43]. This method does not require the cost/criterion functions to be either linear or quadratic but can take on any form desirable to duplicate reality. The SDR was tested by Taubert in a variety of planning situations. In the paint factory application the SDR decisions were only 0.1 percent above the analytically determined optimum computed by the LDR. Other successful applications of SDR include an existing research company, where SDR during a test with actual past data over a 5.5 year period produced highly realistic decisions. The test results indicated that the SDR decisions would have produced a potential 11.9 percent cost saving over the actual management decisions. In a recent simulation test conducted by Lee and Khumawala [26] using both perfect and imperfect forecast data SDR has outperformed Bowman's Management Coefficients Model, the Linear Decision Rule and Jones' Parametric Production Planning Model. Thus, SDR seems to have significant potential for the solution of more realistic planning models. Therefore, the SDR approach has been selected for use in this research project for developing an aggregate production planning system for

small manufacturing industries.

1.3 Scope

The aggregate production planning system designed herein is structured around the Search Decision Rule. The computational model for the system is designed to handle deterministic data only. The system programs consist of: (1) a main routine which contains the master control strategy; (2) a planning cost subroutine for computing the costs and the criterion functions; and (3) a search routine, the "subroutine PATS" taken from reference [40]. The programs are designed to work out near optimum values of the independent decision variables (direct and indirect work force levels and production volumes by product line) for each period. The system programs have built-in routines to compute various planning details based on the optimum values of the independent decision variables. These details include the amount of overtime, the level of plant capacity utilization, and the period/month ending inventory and shortages levels for each product line. The planning cost subroutine is designed to compute various operating costs such as regular payroll, overtime, hiring and training, employee termination, shift premiums, inventory holding, backordering, and production fluctuation costs.

The system has been tested using a hypothetical production planning situation representing a realistic planning environment. The system performance was assessed on the

basis of this preliminary testing and conclusions were drawn and listed in the report. The next logical step is to test the system empirically in actual factory planning situations in order to make desirable refinements. Suggestions have been made which should be helpful in refining the model for use in a practical environment.

CHAPTER 2

THE AGGREGATE PRODUCTION PLANNING SYSTEM

2.1 System Overview

The aggregate production planning system, presented herein, is a time-shared type computer-based system. The system generates all pertinent planning and cost information necessary for scheduling a suitable production plan to meet the sales projections. Ideally, for the most effective operation, the system should be administered and made available for use to small manufacturers through a service organization.

The entire system is sub-divided into functional sub-systems in order to proceed with the development and the ultimate design of the total system in an organized manner. These sub-systems are:

A. Input information management system.

B. Optimization system.

C. Planning data generating system.

Each sub-system is described in detail below.

A. Input Information Management System

The input information management system controls all the input information flows into and within the aggregate production planning system. The input information consists

of management assumptions about the company's goals and objectives including such information as the sales forecast data, operating constraints, production cost data and planning horizons. The system function begins by processing the raw data to prepare a workable data base.

B. Optimization System

The optimization system is designed within the basic framework of the SDR strategy. Under the SDR approach the problem is defined as a multi-stage decision model and solved for a global optimum through use of a computer search technique by optimizing each stage over multi-period planning horizons. Where, a stage refers to any particular point in time when the decisions are to be made, it is usually, but not necessarily, monthly.

The optimization system consists of: (1) a planning cost model which defines the cost structure of the firm; (2) a set of constraints to define the boundaries of the solution space; and (3) an optimization technique (the computer search routine). The system program contains, (1) a master control routine (included in the main routine) to operate the system according to the SDR stragegy; (2) a planning cost subroutine to compute various costs, planning details and the value of the objective function during each iteration; and (3) a search routine, "the subroutine PATS" taken from reference [40]. The subroutine PATS seeks optimum values for the independent variables (production levels

for each product line and the sizes of direct and indirect work forces) for each period in the entire planning span through an iterative process directed by the master control program. It does so by minimizing the value of the objective function which is the sum total of the variable production costs over the planning horizon and the penalty charges for violating one or more of the operating constraints. The variable production costs include such costs as the work force payroll, overtime, employee hiring and training and termination, shift premiums, inventory carrying, backordering and the production change costs. The optimization of each stage's decisions is accomplished through continuous interaction between the search routine and the planning cost subroutine. The entire optimization process and the complete search procedure are described in detail in Section 4.3.

C. Planning Data Generating System

The planning data generating system receives optimal values of the independent decision variables from the optimization system. The system routines then compute and output, for management, all the necessary planning details, such as the amount of overtime, level of the plant's capacity utilization, inventory and shortages levels, work force, inventory holding, backordering and other operating costs (listed in Section 2.3).

The results of each run are reviewed by management

and if desired, the system is rerun with an alternate set of assumptions. This process is repeated until a solution acceptable to management is obtained.

The structure of the computational algorithm designed for the system is illustrated in Figure 2.1. This figure also depicts how the computational algorithm fits into the framework of the sub-systems.

2.2 Input Information Requirements and Data Formats

The entire input information required to initiate a run on the aggregate production planning model has been classified into different data set categories from the standpoint of programming. Included in this section is a complete description of the total input information requirements and the details of the input data format specifications (i.e., how the input data is to be punched on the cards).

Before discussing the input information requirements some of the terms used in this section are defined.

Stage. In the aggregate planning system, using the search decision rule the entire planning problem is defined in terms of a multi-stage decision model, where each stage represents a point in time (the beginning of each successive month/period) when the decisions are to be made concerning the operations of the firm.

Planning Horizon. The planning horizon is the time span over which the operation of the system (firm) is to

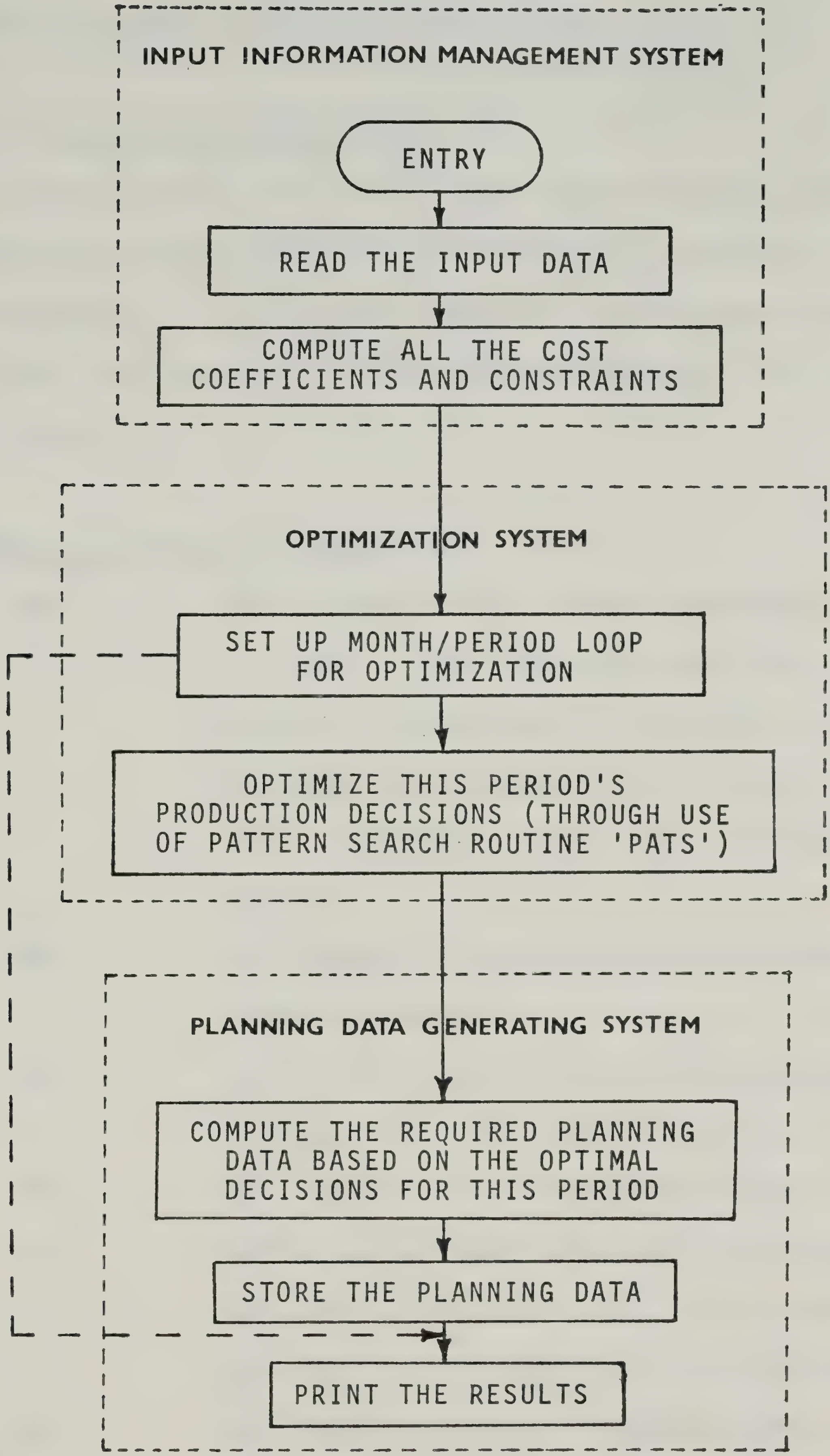


Figure 2.1: Flow Chart of the SDR - Computational Model for the Aggregate Production Planning System

be optimized during each planning stage.

2.2.1 List of the Input Data

In the list given below, each input data-variable is described along with the corresponding notation used to represent it, in the same sequence (under each respective data set class) as it has to be punched on the input data cards.

A. Master Control Variables

(1)	NOY	the length of the entire planning span in years. This variable must be a whole number. Therefore, if its value is in between two integers it should be rounded off to the next higher whole (integer) number.
(2)	NPY	the number of periods per year, must be a whole number.
(3)	NH	the number of periods in each planning horizon, must be a whole number.
(4)	NHM	the number of periods/months which would serve as an upper limit on the length of the planning horizon. It is used for convenience in handling the input data.
(5)	JJ	the total number of product lines or groups being manufactured by the firm.
(6)	NHP	the number of regular hours of work in

each period/month.

(7) JPROPX corresponds to a technique developed by T. Sikes [40] in which an arbitrary factor (JPROPX $\geq$ 1) is used to maintain the month/period ending inventory level close to the desired minimum level. It does so by penalizing the inventory deviations from the specified level for the periods close to the end of the planning horizon. The higher the value of this variable the more effective it is. Its value can be set anywhere between 1 and 50 (it is quite effective for values between 10 and 15). JPROPX can be made totally ineffective by setting it = 1.

(8) NWI a controlling variable, whose value is either one or zero, branches the choice of approach for estimating the indirect work force requirements in the model. Regression method is used when the value is one. Extrapolation is used when the value is zero.

(9) MX an upper limit on the maximum number of shifts, the plant can be operated.

(10) KPRESS a print-out control character equal to one or zero, (suppresses a large fraction

(99 percent) of the detailed output of the analysis when the value is set equal to one and allows the full details to be printed out when its value is equal to zero.

(11) LIM — an approximate upper limit on the total number of search iterations (for optimization) during each stage. Its value is usually set at 3000 (see Appendix I) for more details.

B. Data Set - Type 1

This set contains information regarding the initial conditions at the start of the first planning stage.

(1) OWD — the beginning direct work force level at the start of the month/period one.

(2) OWI — the beginning indirect work force level at the start of the month/period one.

(3) OED — the average employee efficiency level of the direct work force at the beginning of the period one.

(4) OEI — the average employee efficiency level of the indirect work force at the start of the period one.

(5) OTDPI — the level of the direct work force overtime, expressed as a fraction of the work force level, used during the period

prior to the start of the plan.

(6) OTIPI — same as above, for the indirect work force.

(7) MSO — the number of shifts, the plant was operating in prior to period/month one.

C. Data Set - Type 2

This set consists of all the information which is different for each product line and, hence, will be entered into the data file as separate sub-sets (one per product line).

(1) OP — the production level during the period/month prior to period/month one.

(2) OVI — the beginning inventory level at the start of month/period one.

(3) S — the sales forecast for a number of periods/month = NOY x NPY + NHM - 1 (see the master control data set for the definitions of these variables).

(4) VIL — the lower limits on the levels of the month/period ending inventory stocks for each year of the plan.

(5) VIU — the upper limits on the levels of month/period ending inventory stocks, for each year in the plan.

(6) ICR — the cost of carrying inventories per dollar value of the total inventories.

ICR is computed by summing up the following rates:

RMAR = the management's desired after-tax rate of return on its investments.

ISR = the cost of inventory losses through breakage and pilferage per dollar value of the total inventories.

ISOR = the cost of inventory losses through obsolescence and decomposition of the product per dollar value of the total inventories.

IITR = the insurance and tax costs per dollar value of the total inventories.

IOFR = the overhead costs of carrying inventories per dollar value of the total inventories.

(7) PSL the desired upper limit on the level of inventory shortages (expressed as a fraction of the sales).

(8) CPR the cost (per unit) of processing the customer requests for better delivery periods for the sales orders postponed because of a stock shortage.

$$CPR = \frac{F}{M \cdot (AOS)}$$

where

F = the (expected) total annual costs of processing these requests.

M = the average number of orders (per year) met by shortages.

AOS = the average order size, number of units per order.

(9) CGW the cost of goodwill (per unit) that will be lost if a distributor terminates his business with the manufacturer.

$$CGW = g \cdot \left(\frac{ASC}{AOS}\right) \cdot (p/a)$$

where,

g = the management's desired after-tax rate of return on the costs.

ASC = the average dollar value of sales per distributor measured in terms of the costs.

AOS = the average size of a sales order (i.e., the number of units per order).

(p/a) = the present value factor

$$= \frac{1}{i} \{1 - (1+i)^{-2}\}$$

where

i = the management's desired after-tax rate of return on its investments.

(10) P_1 the probability that the requests for improvements in delivery periods will be received if the sales deliveries were postponed because of the stock shortages.

(11) P_2 the probability that an order will be cancelled if it is met with a condition of stockout.

(12) P_3 the probability that the distributor will terminate business with the manufacturer (for this particular item only) if the deliveries are postponed because of stock shortages.

(13) TPTU the average production time (man-hours) per unit of the product line. This should be determined as:

$$TPTU = \frac{1}{\sum_{i=1}^{k} SJ(i)} \left\{ \sum_{i=1}^{k} TPTU(i) \times SJ(i) \right\}$$

where

i = 1,2,3,...,k, the i^{th} product-item in the product line.

SJ(i) = the average yearly sales level

for the product-item (i).

TPTU(i) = the production time (man-hours) per unit for the product-item (i) (its value is equal to the inverse of the production rate).

(14) AI — the average volume of the inspection and quality control work-load, man-hours per unit of the product line. Its value may be set = 0 if NWI = 1 in the master control data.

(15) CDMU — the average cost of direct materials per unit of the product line. For a more complete definition refer to Section 3.9.

D. <u>Data Set - Type 3</u>

This set includes the information which is required separately for each individual year in the entire planning period.

(1) AED — the total yearly depreciation costs.

(2) ARM — the annual expenses for repairs and maintenance of buildings and office equipment.

(3) ARN — the yearly rental costs.

(4) AUT — the utility expenses for each year.

(5) AOS — the yearly expenses of the office supplies.

(6) APT — the yearly insurance and property tax

expenses.

(7) ADD the annual engineering and drafting expenses.

(8) ASW the yearly costs of scrap, rework and in-house material losses.

(9) ASO the yearly costs of outside services such as contract services and travel expenses.

(10) AIS the yearly indirect overhead expenses such as personnel support and training department expenses.

(11) COER the rate for the costs of operation, repairs and maintenance of the plant equipment and machines, dollars per production man-hours.

(12) CPER the rate for the power and electricity costs, dollars per production man-hour.

(13) MDHU1 the maximum direct work force requirements (man-hours per period), for each year, to operate the plant during the first shift without any overtime

(14) MDHU2 the maximum direct work force requirements (man-hours per period), for each year, to operate the plant during the second or each subsequent shift without any overtime.

(15) MDHL1 the minimum direct work force requirements (man-hours per period), for each year, to operate the plant during the first shift

without overtime.

(16) MDHL2 the minimum direct work force requirement (man-hours per period), for each year, to operate the plant for the second or each subsequent shift without overtime.

(17) WI1 the maximum indirect work force requirements (number of employees), for each year, to operate the plant during the first shift without overtime. In case it is difficult to estimate its value, set it = 0 and the model will extrapolate the value internally.

E. <u>Data Set - Type 4</u>

This data set consists of the miscellaneous type of information.

The variables numbers 1, 2, 3, 7, 8, 9 and 10 (listed below) become inoperative when NWI = 1 in the master control data. Hence, their values may be set = 0 when NWI = 1. Similarly, variables numbers 4, 5 and 6 may be set = 0 when NWI = 0.

(1) XI1 the minimum indirect work force requirements (the number of employees) for operating the plant during the first shift without overtime.

(2) XI3 the minimum number of indirect work force employees required to maintain the plant

(operations) during the first shift for a zero direct work force level.

(3) XI4 — the minimum number of indirect work force employees required during the second or each subsequent shift to maintain the plant (operations) for a zero direct work force level during that shift.

(4) X — the regression coefficient, see Appendix 3.

(5) Y — the regression coefficient, see Appendix 3.

(6) Z — the regression coefficient, see Appendix 3.

(7) AS — the number of supervisors required per employee of the direct work force.

(8) AM — the average volume of plant repairs and maintenance work load (man-hours) per production man-hour.

(9) AP — the volume of planning, scheduling, routing and inventory and stores work in man-hours per production man-hour.

(10) AC — the number of truckers, shipping and time clerks required per employee of the direct work force.

(11) PP — the ratio of the number of production planning and scheduling employees to the total number of employees of the indirect work force.

(12) PD1 — the average proportion of hirings in the direct work force from skilled or experi-

enced type of employees, referred to as class (a).

(13) PD2 — the average proportion of the direct work force employees hired from unskilled or semi-skilled type of employees, referred to as class (b).

(14) EHD1 — the average initial efficiency, at the start of the training period, of the direct work force employees from class (a). Assuming 1.0 as the efficiency level for an average trained employee.

(15) EHD2 — the average initial efficiency, at the beginning of the training period, of the direct work force employees hired from class (b). Assuming an efficiency level equal to 1.0 for an average trained employee.

(16) NHTD1 — the average duration of the training/learning period in hours for the direct work force employees from class (a).

(17) NHTD2 — the average duration of the training/learning period in hours for the direct work force employees from class (b).

(18) STD1 — the average proportion of each hour the supervisor spends in directly training each new employee of the direct work force from class (a).

(19) STD2 the average proportion of each hour the supervisor spends in directly training each new employee of the direct work force from class (b).

(20) RD the effective learning rate constant (for the combined plant operations) for the direct work force employees. A method for estimating this learning rate constant is described in the Appendix 4.

(21) CRSD the average recruitment and selection costs for hiring a direct work force employee.

(22) CTFHD the fixed costs of training for the direct work force per trainee, per hour.

(23) PHDU the upper limit on the rate of hiring in the direct work force in any period/month.

(24) PI1 the average proportion of hiring in the indirect work force from skilled/experienced employees, referred to hereafter as class (a).

(25) PI2 the average proportion of the employees hired in the indirect work force from unskilled or semi-skilled employees, to be referred as class (b).

(26) NHTI1 the average duration of the training/learning period in hours for the indirect work force employees from class (a).

(27) NHTI2 the average duration of the training/

learning period in hours for the indirect work force employees from class (b).

(28) EHI1 the average initial efficiency, at the start of the training period, of the employees hired in the indirect work force from class (a). Assuming an efficiency level equal to 1.0 for an average trained employee.

(29) EHI2 the average initial efficiency, at the beginning of the training period, of the indirect work force employees from class (b). Assuming 1.0 as the efficiency level for an average trained employee.

(30) STI1 the (average) proportion of each hour the supervisor spends in directly training each new indirect work force employee from class (a).

(31) STI2 the (average) proportion of each hour the supervisor spends in directly training each new indirect work force employee from class (b).

(32) CRSI the recruitment and selection costs for hiring a new employee in the indirect work force.

(33) CTFHI the fixed costs of training for the indirect work force employees per trainee, per hour.

(34) PHIU — the upper limit on the rate of hiring in the indirect work force in any period/month.

(35) RI — the average (effective) learning rate constant for the indirect work force employees. Its value can be determined in the same way as explained earlier for variable number 20 (RD), or it may be set at approximately 0.75 to 1.00.

(36) PTDU — the upper limit on the rate of terminations of the direct work force employees in any period.

(37) PTRU — the maximum acceptable rate of employee turnover.

(38) PTIU — the upper limit on the rate of terminations of the indirect work force employees in any period/month.

(39) ES — the expected value by which the average employee efficiency level would drop at the beginning of the period of a new shift program (starting or shutting down an additional shift). The efficiency falls because some of the work force has to be redistributed in the process of the program change. The estimate is to be based upon an efficiency level of 1.0 for an average trained employee.

(40) EP — the expected value by which an employee's efficiency level would drop after some of the operations have been reorganized for changing some of the production output levels. The estimate is to be based upon an efficiency level of 1.0 for an average trained employee.

(41) FDS — the time in hours that would be required by an average employee to recover the efficiency lost in the process of a shift program change.

(42) FDP — the time in hours that would be required by an average employee to recover the efficiency lost in the process of changing the production schedules (changes in production levels).

(43) CIF — the expected standby expenses of idle facility (the entire plant) for a period of one year.

(44) POTU — the upper limit on the (percent) level of overtime, for both types of work force, during any period.

(45) PUTU — the upper limit on the (percent) level of employee idle time, during any period, for both types of work force.

(46) ROT — the rate for overtime (employee wage) premium.

(47) PSP the rate for shift (employee wage) premium.

(48) PMN a factor to be applied to the minimum value amongst sales forecast to determine the lower limits for the production levels. Its value can be set anywhere between 0 and 0.5 (where $0 < PMN \leq 1$).

(49) CRIM the ratio of the total annual indirect material costs to the total annual direct material costs.

(50) ALRD the average hourly wage rate of the direct work force employees, including fringe benefits and all other types of allowances.

(51) ALRI the average hourly wage rate of the indirect work force employess, including fringe benefits and all other types of allowances.

(52) SD the average hourly salary of a supervisor in the direct work force.

(53) SI the average hourly salary of the supervisor in the indirect work force.

(54) CASR the rate for the administration costs, to be applied to the costs of production.

(55) CMER the rate for the marketing and distribution costs to be applied to the costs of production.

(56) RMAR the management's desired minimum after-

tax rate of return on its investments.

(57) g — this variable is the same as RMAR above.

(58) PMX — a factor between 1.3 and 2.0, to be applied to the maximum value among the sales projections to determine the upper limits for production levels during any period.

F. <u>Data Set - Type 5</u>

This data set contains the values of the penalty cost factors which are used during the evaluation of the objective function. These factors are applied to the cost of operations, to charge the penalties for the violation of the environmental constraints on the plant operations. The values of these factors are to be set between zero and one. Any of these factors, if the value is set equal to zero, makes the corresponding constraint totally ineffective. The penalty cost factors are:

(1) F(1) — for exceeding the upper limits on the levels of the inventory stocks.

(2) F(2) — for violating the constraints regarding the levels of stock shortages (expressed as fraction of the sales).

(3) F(3) — for the violation of the upper limit on the level of overtime in the direct work force.

(4) F(4) for the violation of the upper limit on the level of employee idle time in the direct work force.

(5) F(5) for exceeding the upper limit on the level of overtime in the indirect work force.

(6) F(6) for exceeding the upper limit on the level of employee idle time.

(7) F(7) for exceeding the upper limit on the rate of hirings in the direct work force in any period.

(8) F(8) for exceeding the upper limit on the rate of employee terminations in the direct work force in any period.

(9) F(9) for exceeding the upper limit on the rate of hirings in the indirect work force during any period.

(10) F(10) for exceeding the upper limit on the rate of employee termination in the indirect work force during any period.

The values of these factors used in the sample problem, shown in the data (Chapter 5), can be used as reference points for initiating the first run with the problem. But, in the subsequent runs these values should be set through trial and error procedures by increasing the values of those factors for which the corresponding constraints are being violated.

G. Data Set - Type 6

This data set consists of the values for all of the independent decision variables in the first planning horizon. These values are approximate estimates based upon past experience and form a starting solution base (the initial reference point) for intiating the optimization process in the model. This data, in fact, is required only for a number of periods equal to the length of the planning horizon. But, it is necessary that these values be provided for (NHM) periods (see master control data set for the definition of NHM) for convenience in changing the length of the planning horizon during different runs. The data in this set consists of the following information:

(1) WD — the direct work force level for (NHM) periods.

(2) WI — the indirect work force level for (NHM) periods.

(3) R — the production levels for all the product lines for (NHM) periods, in separate sets (one set per product line).

2.2.2 Input Data Formats

A. General Formats

There are two types of cards in the data file:

(a) Indicator cards, which specify the type of data which is to follow.

(b) Data cards, which contain the actual data values.

The indicator cards contain two integer numbers to specify the type of data cards that follow. These cards have the following format:

	Field-1	Field-2
Columns	1-3	4-6
Contents	JA	JF

where JA = the data set type number

JF = the number of (data) variables in this particular data set.

All data cards follow the same general formats, except the master control card (the first data card; the format is shown in Figure 2.3). Each card is divided into six fields as shown in Figure 2.2, one field for each numeric value. The number of fields assigned to each variable vary with the type of data variable. Each is explained in detail below.

B. Notes on Input Data

(a) All numeric values appearing in the fields (1 through 6) of the data cards (except the master control card) are defined by ten characters; these characters can include a decimal point. Specification of a sign is optional; if no sign is specified the plus (+) sign is implied. The position of the sign and the decimal

Fields	1	2	3	4	5	6
Columns	1-10	11-20	21-30	31-40	41-50	51-60
Numeric Values						

Figure 2.2 Format for the Data Cards

Fields	1	2	3	4	5	6	7	8	9	10	11
Columns	1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	41-45	46-50	51-56
Numeric Values											

Figure 2.3. Format for the Master Control Card

point is not fixed in these fields. However, for speed and the avoidance of scaling errors it is strongly recommended that the decimal point be placed in some fixed column in all cards and that there be no blanks between the sign and the most significant digit.

The number may be followed by a decimal exponent, written as the letter E followed by a signed or unsigned one or two-digit integer. It is essential that there be no blanks after this integer number.

(b) All the values appearing on the master control card and the indicator cards have to be integer numbers and must be placed as far to the right (in the fields) as possible so that there are no blank spaces left within the fields at the end of these numbers.

(c) All the values of variables expressed as percents must be divided by 100 before entering them on the data cards. For instance, 56.3% will be entered as 0.563.

(d) The input information will be punched on the cards in the same order in which it has been listed in the input data list.

C. Description of the Data Deck

The organization of the data deck and the manner in which each input information will appear on the data cards is described in detail in this section. But, before pre-

senting these details a few important points must be explained:

(a) The statement, "one variable per card" to follow, means the variable has more than one value in the data and each value will appear one per field on the card.

(b) If the number of values of the variable(s) (being punched) exceed the number of fields available on the card, use more than one card. This applies to all the statements such as: "one variable per field or per card" in the explanations to follow.

(c) Almost all the input variables have been referred to herein by their numbers (for identification purposes) which are as per the input data list (in Section 2.2.1).

All cards in the data deck will be punched and arranged as explained below:

(a) Master control card - to have one variable per field.

(b) Cards for data set - type 1.

(i) Indicator card, to have a number 1 in column (3) and a number 7 in column (6).

(ii) Data cards will have one variable per field for all the variables in this set.

(c) Cards for data set - type 2. These cards will contain one set of cards per product line, where each set consists of:

(i) Indicator card, to have a number 2 in column

(3) and a number 15 in columns (5) and (6).

(ii) Data cards:

- One variable per card for variables (1) and (2).
- One value per field for variable (3) (sales forecast data).
- One variable per card for variables (4) and (5).
- One variable per field for variables 6 to 15.

(d) Cards for data set - type 3.

(i) Indicator card, to have a number 3 in column (3) and a number 17 in columns (5) and (6).

(ii) Data cards will have one variable per card for all the 17 variables in this data set.

(e) Cards for data set - type 4.

(i) Indicator card, to have a number 4 in column (3) and a number 58 in columns (5) and (6).

(ii) Data cards will have one variable per field for all the 58 variables in this set.

(f) Cards for data set - type 5.

(i) Indicator card to have a number 5 in column (3) and a number 10 in columns (5) and (6).

(ii) Data cards will have one variable per field for all the 10 variables in this set.

(g) Cards for data set - type 6.

(i) The indicator card, to have a number 6 in column (3) and a number 3 in column (6).

(ii) Data cards will have one variable per card for the variables (1) and (2) and one card per product line for the variable number (3).

The listing of the input data deck, for the sample problem used herein to test the model (given in Appendix 2), can be used as a specimen for reference.

2.3 Output (Planning) Information and Data Reporting Formats

The aggregate production planning system generates all pertinent planning information necessary for decision making, which is reported on the output data formats shown in Figures 2.4, 2.5, 2.6, 2.7 and 2.8. These data reporting formats are self-explanatory, hence, do not need to be explained here.

The output information essentially consists of the following:

(1) Aggregate manpower plan - includes both the direct and indirect work force levels for each period/month (in the plan) along with the respective period's capacity utilization factor to indicate the actual utilization of the total (installed) capacity available through all the shifts the plant is (currently) operating.

(2) Aggregate production plan - for each product line, consists of production and ending inventory levels, inventory shortage levels (expressed as a percent of the sales) for each period/month in the plan.

(3) Work force performance analysis - which includes information on average employee's work-efficiency, overtime and employee idle time (the value will be negative in this case) by period/month.

(4) Production work force costs - gives a detailed breakdown of the various manpower costs by period/month and by year.

(5) Total cost of plant operations - provides a complete analysis of the production and operating costs by period/month and by year.

AGGREGATE MANPOWER PLAN

Year	Period /Month	No. of Shifts	Direct Work Force Level	Indirect Work Force Level	Capacity Utilization Factor (%)

Figure 2.4: Reporting Format for the Aggregate Manpower Plan

AGGREGATE PRODUCTION PLAN

PRODUCT LINE - ( )

				Ending Inventory		
Year	Period /Month	Sales Forecast	Production Level	Level	$ Value	Stockouts (%)

Figure 2.5: Reporting Format for the Aggregate Production Plan

WORK FORCE PERFORMANCE ANALYSIS

		Average Employee Performance Efficiency		Employee Overtime/Idle Time (%)	
Year	Period /Month	Direct Work Force	Indirect Work Force	Direct Work Force	Indirect Work Force

Figure 2.6: Reporting Format for the Work Force Performance Analysis

PRODUCTION WORK FORCE COSTS

		Direct Work Force Costs					Indirect Work Force Costs				
Year	Period /Month	Regular Payroll	Overtime	Hiring/ Training	Employee Termination	Shift Premium	Regular Payroll	Overtime	Hiring/ Training	Employee Termination	Shift Premium
Total											

Figure 2.7: Reporting Format for the Production Work Force Costs

TOTAL COST OF PLANT OPERATIONS

Year	Period /Month	Direct Material Costs	Direct Labour Costs	Overhead Costs	Inventory Carrying Costs	Back-Ordering Costs	Production Fluctuations Costs	Administration Costs	Marketing and Distribution Costs	Total Costs
Total										
									Total	

Figure 2.8: Reporting Format for the Total Cost of Plant Operations

CHAPTER 3

BASIC FUNCTIONS USED IN THE MODEL

All the basic production/cost functions used in the aggregate production planning model have been described in this chapter. Each function is explained herein, in brief details, so as to provide the reader with a clear picture of the background, mathematical analysis and the underlying assumptions used in developing these functions.

3.1 Employee Efficiency During Learning Periods

The model for predicting employee efficiency (performance) during the learning period has been developed from the classic learning curve theory. This theory as applied to the learning of industrial jobs involving skills states that the production time declines by some constant percentage every time the number of units made is doubled. It is represented mathematically by a two parameter function:

$$f(v) = a\ v^{b} \qquad [1]$$

and

$$R = \frac{f(2v)}{f(v)} \qquad [2]$$

where $f(v)$ = the time required to make the v^{th} unit

a = the time required to make the first unit

b = a negative constant

R = the learning rate constant, $(0 < R \leq 1)$

solving [1] and [2],

$$R = 2^b$$

or

$$b = \frac{\text{Log } R}{\text{Log } 2} \qquad [3]$$

If $F(v)$ = the cumulative time to produce v units $(v=1,2,3,...,v)$ then

$$F(v) = \sum_{v=1}^{v} f(v)$$

or

$$F(v) \simeq \int_0^v f(v)$$

or

$$F(v) = \frac{a \ v^{(b+1)}}{(b+1)} \qquad [4]$$

3.1.1 Employee Efficiency

An employee's efficiency at any point in time during the learning period can be defined as the ratio of the time required by an average experienced employee to complete job tasks to the time required by the employee under training. The efficiency of an experienced employee is, therefore, defined as 1.00. The efficiency of an inexperienced employee will take on values between 0 and 1.00 depending upon the employee's experience with the job. For the sake of analysis, all new employees are assumed to reach peak efficiency after a certain job experience, supposedly, the same period in each case (say after making x number of units or F(x) hours). Then, the employee efficiency (E) will be

$$E = \frac{f(x)}{f(v)} = \left(\frac{x}{v}\right)^{b}$$

for v = 1

$$E = E_1 = x^{b}$$

so

$$E = E_1 \cdot v^{-b} \qquad [5]$$

eliminating v from equations [4] and [5]

$$E = E_1 \{(\frac{b+1}{a}) \cdot F(v)\}^{(\frac{-b}{b+1})}$$

or

$$E = E_1 \{A \cdot F(v)\}^B \qquad [6]$$

where

$$A = \frac{b+1}{a} \qquad [7]$$

$$B = \frac{-b}{b+1} \qquad [8]$$

For $E = 1.00$ and $v = x$ the equation [6] will give

$$a = (b+1) \cdot F(x) \cdot (E_1)^{1/B} \qquad [9]$$

where $F(x)$ = the time (in hours) to make x number of units or the total job experience required to attain the peak efficiency or in other words the total training period.

3.1.2 Average Employee Efficiency

The average employee efficiency (EA) over a certain length of the period, from $F(v)_1$ to $F(v)_2$ is given by

$$EA = \frac{\int_{F(v)_1}^{F(v)_2} E_1 \{A \cdot F(v)\}^B \cdot d\{F(v)\}}{\{F(v)_2 - F(v)_1\}}$$

or

$$EA = \frac{E_1}{B+1} \cdot A^B \cdot \frac{\{F(v)_2^{(B+1)} - F(v)_1^{(B+1)}\}}{(F(v)_2 - F(v)_1)} \qquad [10]$$

The employee efficiency function is used in the aggregate production planning model to determine the average efficiency of the employees during the training/learning periods. This efficiency is an aggregate value for the total plant and is computed using the effective values for the training period and for the learning rate constant.

3.2 Overhead Costs

Overhead costs are those costs that cannot be clearly associated with particular operations or products and therefore must be prorated by some method. There are many methods whereby overhead costs may be allocated. One should adopt a system that gives the desired accuracy with a minimum of effort on a continuing basis. In this model the overhead costs have been distributed on a man-hour (equivalent of total production) basis:

$$\text{Overhead rate} = \frac{\text{Actual factory overhead expenses}}{\text{Man-hours equivalent of the total production}}$$

or

$$OHR = \frac{AFO}{MHD}$$

where OHR = the overhead rate

AFO = the actual factory overhead expenses

MHD = the direct labour man-hours equivalent of production.

The overhead expenses consist of the following cost items:

(1) Depreciation expenses:

(a) Land and buildings.

(b) Plant equipment, machines and vehicles.

(c) Office equipment.

(2) Rental expenses:

(a) Machines and equipment.

(b) Production space or facility.

(3) Repair and maintenance of buildings and office equipment.

(4) Utilities: water, heating and lighting, etc.

(5) Office supplies.

(6) Property taxes and insurance expenses.

(7) Engineering, design and development expenses.

(8) Scrap, rework and in-house material losses.

(9) Costs of outside services: contract services and travelling, etc.

(10) Indirect overhead expenses:

  (a) Personnel support.

  (b) Training office expenses.

(11) Operating expenses including repair and maintenance of plant equipment, machines and vehicles.

(12) Indirect employees salaries and wages:

  (a) Inspectors.

  (b) Supervisors.

  (c) Repair and maintenance crews.

  (d) Clerical personnel: schedulers, time office clerks, truckers and shipping clerks, etc.

(13) Indirect material costs.

(14) Power and electricity expenses.

3.3 Cost of Production Time

The cost of production time, used in the aggregate production planning model, is defined as the fixed cost of operations per man-hour of the total work force and is computed using the following mathematical model:

$$CPTH = \frac{CFOH}{(WD + WI) \cdot NHP}$$

where CPTH = the cost of production time per man-hour

CFOH = the fixed cost of operations, includes all the cost items from one to ten listed under overhead costs in Section 3.2

WD = the direct work force level

WI = the indirect work force level

NHP = the number of regular hours of work per period.

3.4 Direct Work Force Model

The direct work force consists of all the production workers who are directly engaged in the manufacture of the product, i.e., it includes all workers such as, machine operators, fabricators and assemblers, etc.

In production type industries, the direct work force requirements are usually estimated by various time study methods. This involves dividing operations into their basic elements, applying time factors to these elements and finally arriving at the total time for each operation. The total operation time consists of: the setup time (the time for preparing and setting up the machine for the next production run) and the cycle time or the run time (material handling time, machine time, and any delay times). The total production time, after accounting for man and machine inefficiencies, is then used to ascertain the total direct work force requirements using the following mathematical model:

$$WD^{*} = \frac{1}{NHP} \times \sum_{j=1}^{J} P_j \times TPTU_j$$

where WD^{*} = the direct work force requirements

P_j = the production level

$TPTU_j$ = the expected production time, man-hours per unit of the product line (j)

NHP = the number of regular hours of work, per period

j = a subscript for product lines, $j=1,2,...,J$.

3.5 Indirect Work Force Model

The indirect work force, in a production-type industry, consists of all categories of employees which are supplemental to the direct work force, such as:

(1) Supervisory staff.

(2) Inspectors and quality control personnel.

(3) Maintenance crews.

(4) Planning, scheduling and routing personnel.

(5) Inventory and stores personnel.

(6) Other clerical staff, such as: truckers and shipping clerks, time office and other personnel directly engaged in services concerning production.

Material handlers are also sometimes classified as indirect employees for the convenience of costing. But, in this model this category of employees is assumed to be a

direct work force class.

Two methods have been built into the model to estimate the indirect work force requirements. Either method can be used depending upon the availability of the data.

3.5.1 Regression Method

In this method, the indirect work force is estimated as the function of the direct work force, the form of the regression equation is:

$$WI^* = X + Y(WD)^Z$$

where WI^* = the indirect work force requirements

WD = the direct work force level

X = a constant equal to the minimum level of the indirect work force required to maintain the plant operations at a zero direct work force level

Y and Z are the regression coefficients and will be determined from historical data.

The fortran code for developing this model is given in Appendix 4.

3.5.2 Extrapolation Method

This method should be used when sufficient historical data is not available to develop the regression model.

Here, the indirect work force is expressed as a linear function of direct work force and production levels. The slope coefficients for this equation can be set using intuition/judgment estimates. The form of the mathematical model is

$$WI^* = (AS + AC)WD + \sum_{j=1}^{J} (AI_j \times P_j)/NHP$$

$$+ (AM + AP)WD^* + XI2(S - 1)$$

and

$$WI^* \geq XI1$$

where WI^* = the indirect work force requirements

WD = the direct work force level

WD^* = the actual direct work force requirements

P_j = the planned production level for the product line (j), j=1,2,3,...,J

S = the number of shifts the plant is presently operating

$XI1$ = the minimum indirect work force level required to run the plant for a single shift

$XI2$ = the minimum indirect work force level

required to maintain the plant for the second shift or subsequent shifts.

AS = the number of supervisors required per employee of the direct work force

AI_j = the volume of inspection and quality control tasks in man-hours per unit of the product line (j)

AM = the volume of maintenance work in man-hours per production man-hour

AP = the volume of planning, scheduling, routing, inventory and stores work load in man-hours per production man-hour

AC = the number of all the clerical personnel of category 6 required per employee of the direct work force

NHP = the total number of regular hours of work per period.

3.6 Hiring and Training Cost Model

The cost of hiring and training an employee consists of the following cost components.

3.6.1 The Recruitment and Selection Costs

(a) Advertising costs, including the fees paid to employment agencies.

(b) The costs of making selection decisions.

(i) Salary and wage expenses of the interviewing

staff.

(ii) The costs of materials and equipment used during assessment or tests.

(iii) Employment office overheads.

(iv) Other expenses, such as: physical examination fees, medical and clinical expenses and the costs of verifying the references.

3.6.2 The Training Costs

(a) The fixed costs of training, such as: the cost of training materials, books and reviews, etc.; and the training department overhead.

(b) The costs of productivity losses resulting from inefficiencies of the new employees, during the learning periods. These productivity losses are a maximum in the beginning of the training period and will gradually decrease as the employee's efficiency increases towards the end of the period. The cost of these losses is estimated as the cost of actual production time lost due to inefficiencies and is equal to

$$CPTH(1 - EHA)$$

where CPTH = the cost of the production time per man-hour

EHA = the average efficiency of the employee

during the training period.

(c) The supervision costs, i.e., the cost of the time the supervisor spends in directly training the employee which would not have to be spent if the employee were fully trained to perform his job. The amount of time spent will decrease as the efficiency increases. The actual amount of time spent for an hour is

$$ST(1 - EHA)$$

where ST = the average proportion of each hour the supervisor spends in directly training the new employee

EHA = the average efficiency of the employee during the training period.

Hence the total cost of hiring and training an employee is:

$$CHTA = \text{Recruitment and selection costs} + \text{training costs}$$

$$= CRS + \{CTFH + (1 - EHA) \cdot (CPTH + S \times ST)\} \times NHT$$

where CHTA = the cost of hiring and training an employee

CRS = the recruitment and selection costs per employee hired

CPTH = the cost of the production time per man-hour

CTFH = the fixed costs of training per trainee, per hour

S = the hourly salary of the employee's supervisor

ST = the average proportion of each hour the supervisor spends in directly training the new employee during the entire training period

EHA = the average efficiency of the employees during the training period

NHT = the expected duration of the total training period in hours.

3.7 Employee Termination Cost Model

Termination costs within most companies are usually much more significant than they appear to be on the surface. These costs basically consist of the following.

3.7.1 Cost of Hiring and Training an Employee

An employee is a valuable asset to the company. Therefore, termination of an employee means a net loss equal to the cost of hiring and training the employee.

3.7.2 Cost of Excessive and Frequent Terminations

Very frequent and excessive termination rates create a feeling of job insecurity among the employees who in turn will find other employment and leave the company. As a

consequence, the hiring and training costs increase and the plant production suffers in quality and output declines. This cost has been estimated empirically as the hiring and training cost times the amount by which the average rate of terminations over the past six periods/months exceeds a predetermined level.

Hence, the total cost of terminating an employee is

$$\begin{aligned} \text{CET} &= \text{hiring and training cost} \\ &\quad + \text{cost of excessive terminations} \\ &= \text{CHTA}\ \{1 + \frac{\text{PLM} \cdot W_t}{(W_{(t-1)} - W_t)}\} \end{aligned}$$

where

$$\begin{aligned} \text{PLM} &= \text{PTRW} - \text{PTR} \quad \text{for} \quad \text{PTRW} > \text{PTR} \\ &= 0 \qquad\qquad\qquad \text{otherwise} \end{aligned}$$

PTRW = the average rate of terminations over the past six periods/months

PTR = the maximum acceptable level of labour turnover

CET = the cost of terminating an employee

W_t = the workforce level at the end of the current period

W_{t-1} = the work force level at the end of the previous period.

3.8 Work Force Costs

The work force costs consist of the following costs.

3.8.1 Regular Payroll Costs

These costs are purely the salary and wage expenses of all the employees:

$$CLP = ALR \times NHP \times W_t$$

where CLP = the regular payroll costs

NHP = the number of regular hours of work per period/month

W_t = the work force level during the period (t)

ALR = the average hourly wage rate per employee, inclusive of fringe benefits and all the allowances.

3.8.2 Overtime Costs

In this model it has been assumed that the overtime is used only to meet (temporary) shortages of work force, not other kinds such as the shortage of (installed) production capacity. Thus the overtime cost will be:

$$COT = ROT \times ALR \times NHP \times \left(\frac{W_t^*}{E_t} - W_t\right) \quad \text{for} \quad W^* > W$$

$$= 0 \qquad \text{otherwise}$$

where COT = the overtime costs

ROT = the overtime rate premium

ALR = the average hourly (gross) wage rate

NHP = the number of regular hours of work per month/period

W_t = the work force level during the period

W_t^* = the actual work force requirements for the period

E_t = the average efficiency of the employees during the period (t).

3.8.3 Shift Premium Costs

The shift premiums are paid to those employees who only work in shifts, but here, for convenience in analyzing the costs, it has been assumed that all employees will receive the shift premiums. The shift premium costs are:

$$CSP = (PSP - 1) \times CLP \quad \text{for} \quad S_t > 1$$

$$= 0 \qquad \text{for} \quad S_t = 1$$

where PSP = the rate for shift premiums, ($PSP \geq 1$)

CLP = the regular payroll costs

S_t = the number of shifts the plant operates during the period (t).

3.8.4 Hiring and Training Costs

The employees hired normally have different skill/experience backgrounds. Thus, the job learning/training time will, most of the time, be different in each case. Therefore, in order to maintain uniformity in the analysis, the skill or experience background of the new employees can be broadly classified into the following two categories:

(a) The skilled or experienced class.

(b) The unskilled or semi-skilled class.

The hiring and training costs can be calculated as given below:

$$CHT = CHTA\{W_t - W_{(t-1)}\} \quad \text{for} \quad W_t > W_{(t-1)}$$

$$= 0 \qquad \text{otherwise}$$

where CHT = the total hiring and training costs

CHTA = PH1 x CHTA1 + PH2 x CHTA2

PH1 = the expected proportion of hirings from the category (a)

PH2 = the expected proportion of hirings from the category (b)

CHTA1 = the hiring and training costs per employee from the category (a) (refer to Section 3.4)

CHTA2 = the hiring and training costs per employee from the category (b) (refer to Section 3.4)

W_t = the work force level at the end of the period (t)

$W_{(t-1)}$ = the work force level at the beginning of the period (t).

3.8.5 Employee Termination Costs

These costs are determined as follows:

$$CETW = CET(W_{(t-1)} - W_t) \quad \text{for} \quad W_t < W_{(t-1)}$$
$$= 0 \quad \text{otherwise}$$

where CETW = the total employee termination costs

CET = the employee termination costs per employee (refer to Section 3.7 for a more complete explanation)

W_t = the work force level at the end of the period (t)

$W_{(t-1)}$ = the work force level at the beginning of the period (t).

The (total) work force cost is obtained by summing all the cost components listed above. Thus, the work force cost (CW) is:

CW = Regular payroll costs + Overtime costs
+ Shift Premium costs + Hiring and training costs

+ Employee termination costs.

3.9 Direct Material Costs

Direct Materials are all those materials (used in manufacturing) which become a part of the final product and are involved in the operation in such a way that the material cost can be estimated. The major component of the direct material cost can be derived by completing a material take-off from the product blueprint(s). To this material cost one must add scrap material costs which are represented by two components: (1) scrap due to waste material, such as, slugs that are discarded from punching a hole in the component being manufactured and (2) components that have to be scrapped due to such factors as workmanship and machine misalignment.

The mathematical model for the total direct material costs is:

$$CDMT_t = \sum_{j=1}^{J} P_{tj} \cdot CDMU_j$$

where $$CDMU_j = \frac{\sum_{p=1}^{P} CDMU_{pj} \times SA_{jp}}{\sum_{p=1}^{P} SA_{jp}}$$

$CDMT_t$ = the total direct material costs for operations during period (t)

$CDMU_{pj}$ = the direct material costs per unit of the p^{th} product item in the j^{th} product line

$CDMU_j$ = the expected direct material cost per unit for the product line (j)

SA_{jp} = the annual sales level for the p^{th} product item in the j^{th} product line

P_{tj} = the production level for the product line (j) during period (t).

3.10 Indirect Material Costs

Indirect materials are those materials which are critical to the operation (for manufacture) but do not become a part of the final product. This may include cutting lubricants, welding rods, perishable tools and clerical supplies. Because these costs are difficult to assess, it is charged to the product cost through an overhead distribution based upon direct material cost:

$$CIM = \left(\frac{CIMA}{CDMA}\right) \times CDM$$

where CIM = the cost of indirect materials

CDM = the cost of direct materials

CIMA = the total yearly indirect material costs

CDMA = the total yearly direct material costs.

3.11 Inventory Carrying Costs

Inventory carrying costs are the costs of maintaining inventory stocks in a production and/or distribution system. These costs basically consist of the following cost components:

(1) Opportunity cost of capital invested in inventories. This cost is equal to the company's desired after-tax rate of return on its invested capital.

(2) Shrinkage losses, the loss through breakage and pilferage at the storage site.

(3) Loss through aging due to decomposition and/or decay of the products on shelves (with time) or decline in value of the products in storage due to obsolescence.

(4) The cost of insurance and taxes.

(5) Overhead or fixed costs. These include:

(a) Depreciation and/or the rent of the storage facility.

(b) Operating expenses:

(i) Operating and maintaining the equipment.

(ii) Utilities expenses.

(iii) Salaries and wages of the staff.

All of these costs vary directly with the amount of investment in inventories, therefore, can be estimated as rates per dollar value of the inventory stock. Hence, the total inventory cost function will be:

$$ICR = RMAR + ISR + ISOR + IITR + IOFR$$

where ICR = the rate for inventory carrying costs as a percent of the total inventory value

RMAR = the company's desired after-tax rate of return on its invested capital

ISR = the rate for the shrinkage losses as a percent of the total inventory value

ISOR = the rate of loss through decomposition and obsolescence as a percent of total inventory value

IITR = rate of insurance and property tax expenses as a percent of the total inventory value

IOFR = rate for overhead costs of inventories as a percent of total inventory value.

In the criterion function, the inventory carrying costs serve to penalize the undesirable stock surpluses. Therefore, for use in the objective function, the inventory carrying costs are computed for the surplus stock levels only, i.e., for the number of units above the safety or minimum reserve stock level. But, for all other costing purposes the inventory carrying costs are computed corresponding to the actual stock levels.

3.12 Inventory Shortage Costs

Inventory shortage costs are the costs incurred as a consequence of stock out. That is, when the demand cannot be fully and immediately satisifed due to a stock shortage. The shortage costs consists of the following cost

components.

3.12.1 The Cost of Processing the Requests for Improvements in Delivery Dates

As a result of inventory shortages the deliveries for all the orders falling under shortages are postponed and the customers and/or distributors are informed about the expected delivery periods. Consequently, most of the customers and/or distributors will ask for better delivery dates from the manufacturer. Then, depending on the production schedule, the manufacturer is either able to give an improved delivery date to the satisfaction of some distributors or is forced to deny the request. But, this will incur costs (labour and communication charges, etc.) to process these requests whether or not the manufacturer is able to give an improved service. These costs of processing the requests (per unit short) are:

$$CPR = \frac{F}{M \cdot (AOS)}$$

where CPR = the average cost to process a request for a better delivery date

M = the average number of stock-outs per year

AOS = the average order size, number of units per order

F = the expected annual costs of processing the requests for better delivery periods.

3.12.2 The Cost of Lost Sales

Some sales may be lost on orders met by the stock out condition, because the customers and/or distributors to whom the late deliveries are not acceptable may cancel their orders for this particular period (for this particular item only). This loss will be equal to the amount of after-tax profit foregone on these sales.

3.12.3 Goodwill Losses

Some customers/distributors who have been given the delayed delivery dates may terminate their business with the manufacturer, supposedly for the item short only. This means a loss of all the future sales, expected through these clients. This loss can be estimated to be equal to the present worth of these sales. For the sake of analysis it is assumed that the distributor who terminates his business with the manufacturer for this item, generally speaking, would resume business after a certain length of time (assumed to be the same in each case, say (q) years).

If P_1, P_2 and P_3 are the probabilities associated with the three cases discussed above, then the expected cost of each unit short will be:

$$\begin{aligned} \text{CINSA} = P_1 &\times \text{Cost of processing the requests for better} \\ &\text{delivery periods} + P_2 \times \text{Costs of lost sales} \\ &+ P_3 \times \text{Cost of goodwill losses per unit} \end{aligned}$$

$$= P_1\left(\frac{F}{M \cdot (AOS)}\right) + P_2(g \times CPU) + P_3\left(\frac{g \times PQI \times ASC}{AOS}\right)$$

where CINSA = the cost of shortages per unit short

F = the expected yearly cost of processing the requests for better delivery periods (includes labour, communication charges, etc.)

M = the average number of stock outs per year

AOS = average order size, number of units per order

g = the rate of (after-tax) profit earned on the cost of sales

CPU = the cost of the product (per unit) before sales

ASC = the average yearly sales per distributor (to be estimated in terms of the cost of sales)

PQI = present value factor.

The inventory shortage costs are subject to estimates of probabilities that the actual demand quantities will exceed stock quantities during the future periods. These probabilities are quite difficult to estimate and would complicate the analysis. Therefore, as an alternative, the method used in the model for estimating this cost presumes that the loss is sustained whenever the actual stock level drops below the safety or minimum reserve stock level. The

number of units below the safety stock level multiplied by the dollar contribution (loss) per unit would give a reasonable estimate of the cost of stock shortages.

3.13 Shift Start-Up and Shut-Down Costs

Start-up or shut-down of an extra shift imposes additional costs which are incurred at the beginning of the period of program change. These costs basically consist of the following cost components:

(1) The cost of additional planning work: to reschedule the man-machine loading; to make adjustments in the production runs; and to work out the new manpower requirements (for hiring/layoffs and overtime).

(2) The cost of productivity lost due to work-inefficiencies resulting from the redistribution of the work force to suit the new shift arrangement. This cost is estimated as the cost of the useful production time lost in the inefficiencies.

The following assumptions have been used in developing the shift start-up and shut-down costs model:

(1) The minimum production capacity (man-hours of direct work force) requirements for starting or continuing the additional shift are assumed to be greater than that available through use of a maximum amount of overtime.

(2) The number of employees redistributed for implementing the new shift program is equal to half the minimum

number of employees required to start an additional shift.

(3) All the additional planning tasks, resulting from the start-up or the shut-down of an additional shift, supposedly would make half a days work for the planning and scheduling employees whose number is equal to the number of total planning and scheduling employees times the (minimum) proportion by which the existing production capacity will be increased or decreased.

The mathematical model for estimating these costs is given below:

$$\begin{aligned} CSS &= \text{Cost of extra planning work} \\ &\quad + \text{Cost of productivity lost} \\ &= 4.0 \times ALRI \times PP \times WI1 \times \left(\frac{MHDL2}{MHDU1}\right) \\ &\quad + 0.25(1 - ES) \times FD(S) \times CPTH \times \left(\frac{MHDL2 + MHIL2}{NHP}\right) \end{aligned}$$

where CSS = the additional shift start-up or shut-down cost

ALRI = the average hourly wage rate for the indirect work force employees

PP = the ratio of the planning and scheduling employees to the total indirect employee

work force

ES	=	the level of work-efficiency at the beginning of the period of the program change (i.e., after a reorganization of the operations)
FD(S)	=	the time in hours required to regain the peak work-efficiency (100%)
CPTH	=	the cost of the production time per man-hour
NHP	=	the number of regular hours of work per period/month, per employee
MHDL2	=	the minimum production capacity (man-hours of the direct work force) requirements for the start-up or shut-down of an additional shift
MHIL2	=	the minimum requirements for the indirect work force (man-hours) in the second and each subsequent shift
MHDU1	=	the maximum production capacity (man-hours of direct work force) available in the first shift
WI1	=	the indirect work force requirements for the first shift at full production capacity.

3.14 Costs of Fluctuations in Production Levels

The costs of fluctuations in the production levels may be classified into the following two groups:

(1) The expenses are those incurred only once at the beginning of the period of the new program. These include:

(a) Hiring and training costs.

(b) Employee termination costs.

(c) Shift start-up and shut-down costs.

(d) The cost of productivity lost due to the work-inefficiencies resulting from the redistribution of the work force in order to adjust to (a) the changes in the work force levels (hirings and terminations) and/or (b) the changes made in the set-up of the production lines or the work centres. This cost will be estimated as explained in the previous section.

(e) The cost of additional planning work resulting from the changes in the production programs. This includes the tasks such as: rescheduling the man-machine loading and the production runs; and the manpower planning.

(2) The expenses that may be imposed for the duration of the period of the new program. This includes:

(a) The overtime expenses.

(b) The costs of shift premiums.

(c) The standby expenses of idle facilities.

All of the cost items except 1(c), 1(d) and 1(e) have been considered in the aggregate production planning model separately for the sake of convenience in the analysis.

Therefore, the costs of fluctuations in production levels will consist of the cost items 1(c), 1(d) and 1(e) only.

In order to facilitate the mathematical analysis of this model the following set of assumptions has been used:

(1) The total number of employees redistributed (as a part of the process of reorganizing the operations):

(a) in case of hirings or terminations, is equal to half the number of employees hired or terminated;

(b) in case of a change in the production level, their proportion is equal to the proportion by which the production level has changed.

(2) The additional planning tasks are assumed to be three hours of work for the planning and scheduling employees whose number is equal to the number of the total planning and scheduling employees times the proportion by which the production level has changed.

The mathematical model for these costs is as given below:

CCP_t = Costs of inefficiencies resulting from changes in production levels + costs due to additional planning tasks + shift start-up and shut-down costs.

$$= 0.5\{0.5(\Delta WD_t + \Delta WI_t) + PMHD_t(WD_{(t-1)} + WI_{(t-1)})\}$$

$$\times (1 - EP) \times FD(P) \times CPTH + 3.0 \times ALRI \times PP \times WI_t$$

$$\times PMHD_t + CSS \times S$$

where $\Delta WD_t = |WD_t - WD_{(t-1)}|$

$\Delta WI_t = |WI_t - WI_{(t-1)}|$

$$PMHD_t = \frac{\sum_{j=1}^{J} |MHD_{tj} - MHD_{(t-1)j}|}{\sum_{j=1}^{J} MHD_{tj}}$$

t = a subscript for periods/months, $t=1,2,3,\ldots,t$

j = a subscript for product lines, $j=1,2,3,\ldots,J$

CCP_t = the costs of fluctuations in production levels

WD_t = the direct work force level

WI_t = the indirect work force level

MHD_{tj} = the production of the product line (j), man-hours of direct work force

CPTH = the cost of the production time per man-hour

CSS = the shift start-up and shut-down costs per shift started or shut-down

S = the number of additional shifts started or shut-down

NHP = the number of regular hours of work per employee, per period

ALRI = the average hourly wage rate for the indirect work force employees

PP = the ratio of the production planning and scheduling employees to the total indirect

employee work force

EP = the expected work-efficiency level in the beginning of the period of the new program (i.e., after reorganizing the operations)

FD(P) = the expected time in hours required to regain the peak work-efficiency level (100%) after a change in the production program.

3.15 Unit Manufacturing Cost

The manufacturing cost consists of the direct material costs, the direct labour costs and the overhead costs. The mathematical model is as given below:

$$CPU_j = CDMU_j + TPTU_j(CDWH + COHR)$$

where CPU_j = the manufacturing cost per unit

$CDMU_j$ = the direct material costs per unit

$TPTU_j$ = the production time, man-hours per unit

COHR = the overhead rate, dollars per production man-hour

CDWH = the labour rate, dollars per production man-hour

j = a subscript for the product lines, $j=1,2,3,\ldots,J$.

3.16 Total Cost of Operations

The total cost of operations is obtained by summing the following set of costs:

(1) Direct work force costs - are the labour costs associated with specific machine operators.

(2) Direct material costs - are the costs of all those materials which are directly consumed in the manufacture of the product (including scrap).

(3) Overhead costs - includes such costs as rents, depreciation, taxes, maintenance, indirect materials, indirect work force, power and electricity, heat, light, water and utilities.

(4) Inventory carrying costs - are the costs of maintaining (carrying) the inventory stocks.

(5) Inventory shortage costs - are the costs of expected losses that will be incurred when an order is met by a condition of stock shortage. These are intangible costs and are assessed through probabilistic estimates (very approximate). Even then, these costs are of great significance in the analysis.

(6) Costs of fluctuations in production levels - are the costs of productivity lost due to the work-inefficiencies resulting from the redistribution of the work force and reorganization of operations necessary for a new production program.

(7) Marketing and distribution costs - consist of such items as salaries and commissions for sales personnel,

advertising, entertainment and travel expenses.

(8) Administration costs - consist of such cost items as salaries and allowances of management personnel, wages of clerical and accounting staff, office rent and supplies and utilities.

The last two costs (numbers 7 and 8) will be estimated through fixed rates applied to the total production costs (the sum total of the first six costs). The costs of operations computed, herein, do not include any profits. But, the gross profits can be added separately, to arrive at the cost of sales, through a rate applied to the cost of operations. It may be mentioned here that the system routines are designed to calculate the cost of operations only, not the cost of sales.

CHAPTER 4

OPTIMIZATION MODEL

The optimization of the decisions in SDR involves the act of selecting the "best" solution from among a set of feasible alternatives. The entire optimization model has been sub-divided into: a planning cost model - to compute the production costs and the criterion function; a set of constraints to define the decision space; and an optimization technique - a computer search routine to select the best feasible solution. Each is discussed below in details.

4.1 Planning Cost Model

The planning cost model determines the cost of operations over the planning horizon and, hence, the objective function for evaluating the performance of the system (firm). The flow chart shown in Figure 4.1 provides a detailed description of the planning cost model. The Fortran equations for the model are contained in the documented listing of the subroutine FCT1, given in Appendix 2.

The model, virtually operates the system (firm) for each month over the planning horizon based upon the decisions supplied by the pattern search routine. This operation consists of costing out the impact of the decisions in each

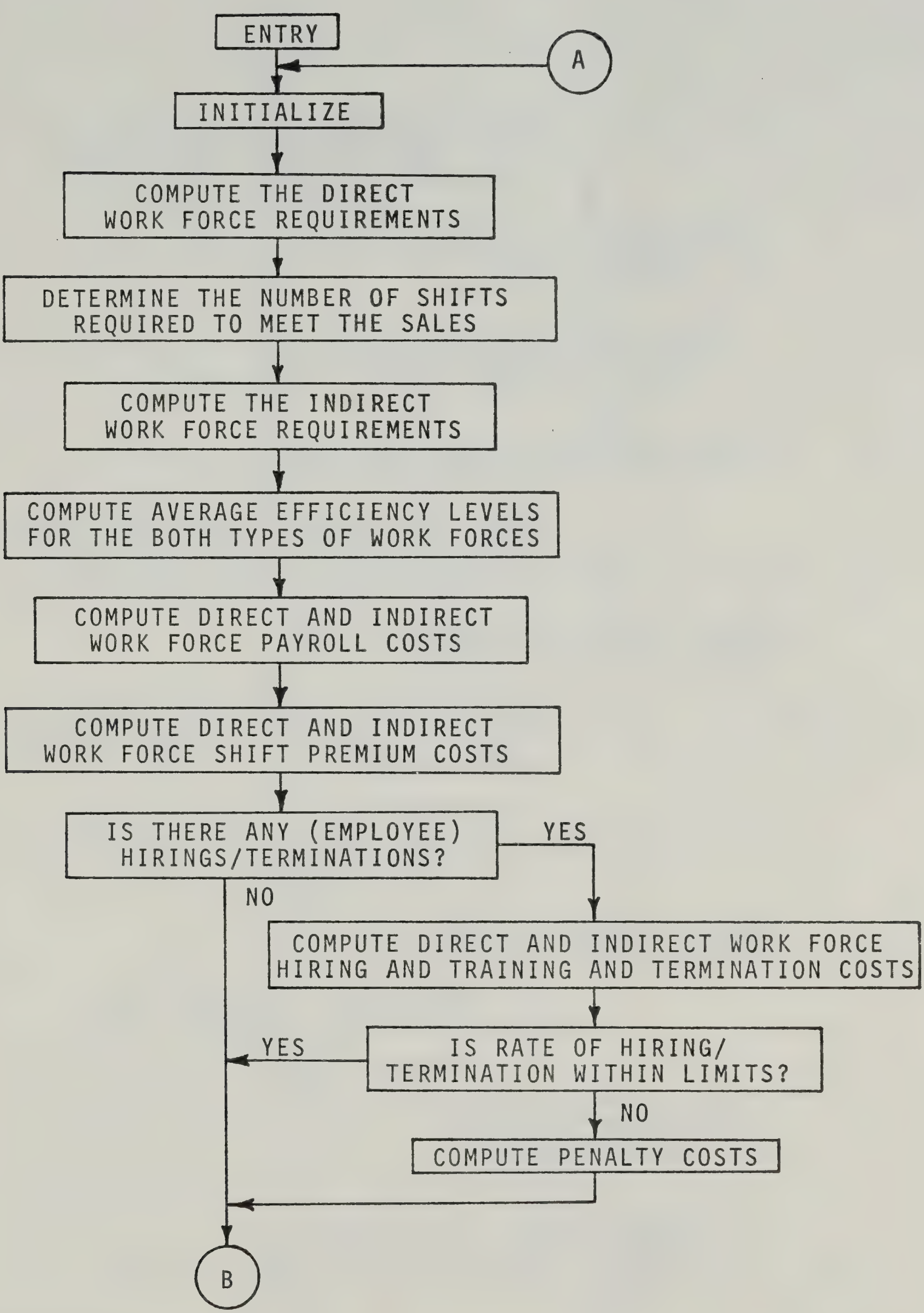


Figure 4.1: Flow Chart of the Planning Cost Model

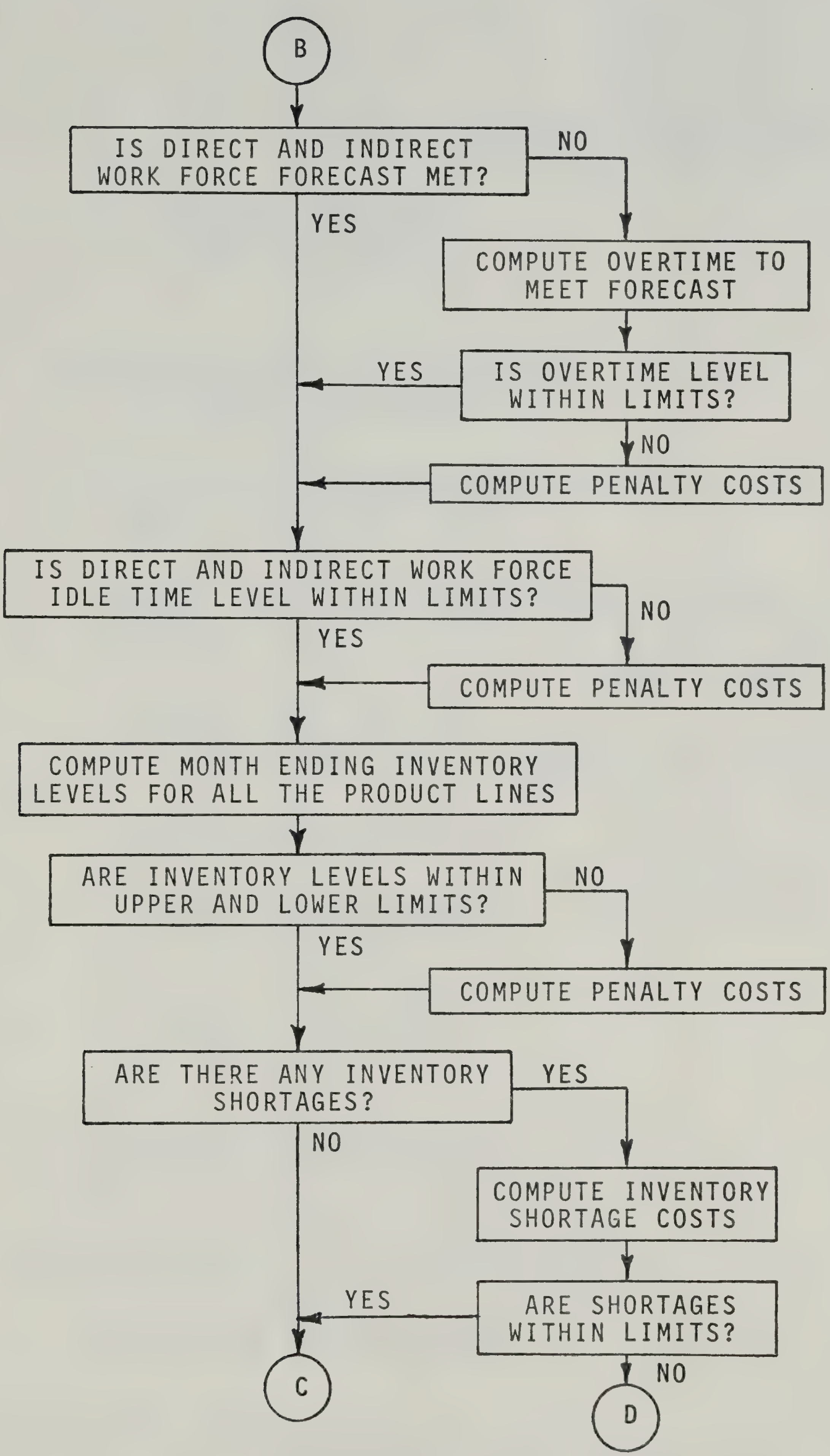


Figure 4.1: (Continued)

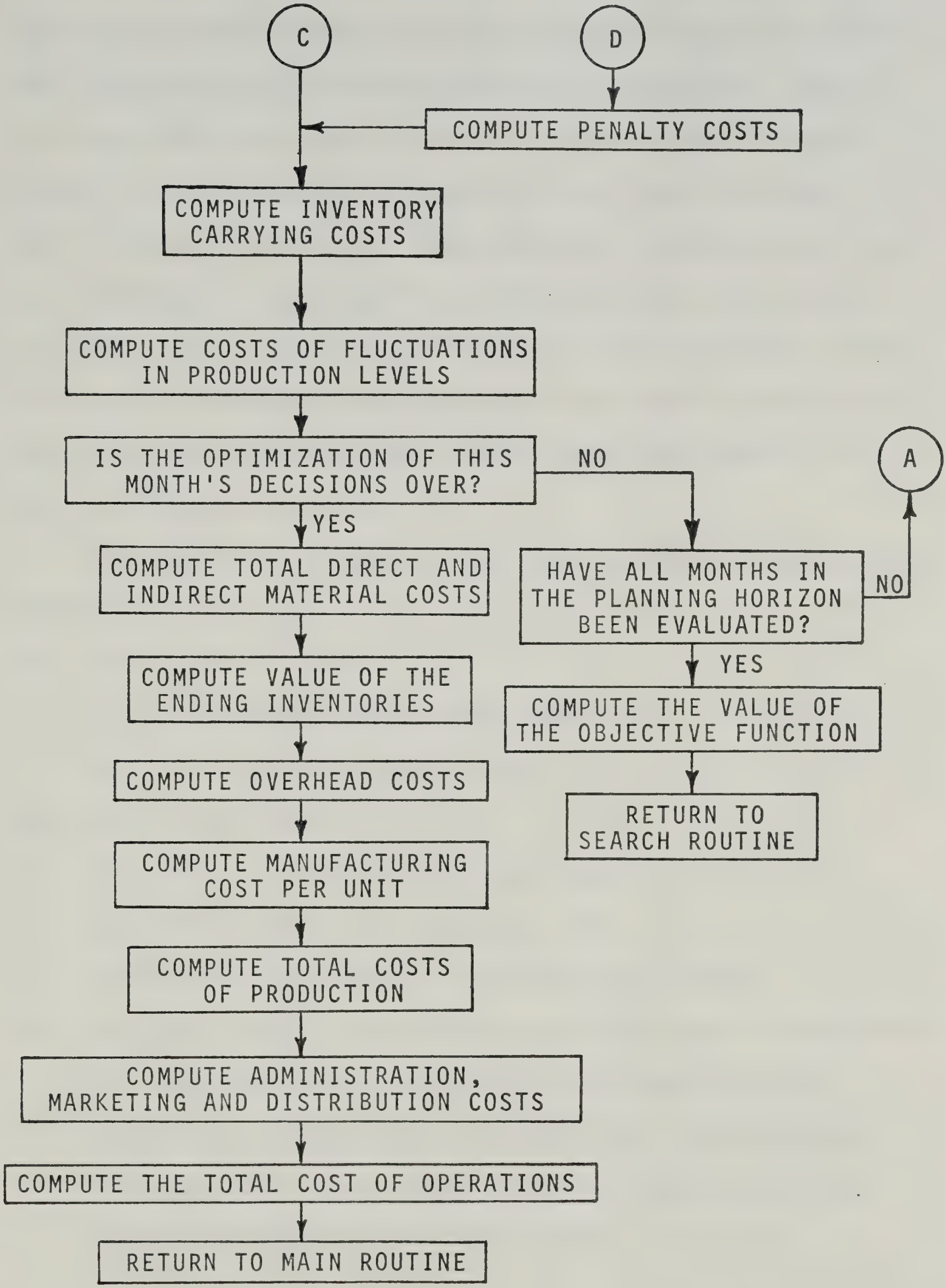


Figure 4.1: (Continued)

month and computing the various cost penalties for violating the constraints on the production parameters. The critical operating costs are then totaled (for all the months in the planning horizon) and the penalty costs added to get the value of the objective function which is then returned to the search routine where it is assessed to establish the next move for a new trial solution. After the search terminates the planning cost model computes all the planning data required for reporting the results of this period's decisions.

The objective function consists of the following cost components:

(1) Work force costs:

 (a) The direct work force costs.

 (b) The indirect work force costs.

(2) Inventory costs:

 (a) The inventory carrying costs.

 (b) The inventory shortages costs.

(3) Costs of fluctuations in production levels.

(4) Penalty costs - charged for violating the constraints on the production parameters (discussed below). These are charged in such a way that the amount of the penalty cost is proportional to the amount by which the constraint is exceeded.

4.2 Set of Constraints

The constraints used in the aggregate production

planning model are classified as follows:

(1) The range constraints for the decision vectors (production, direct work force and indirect work force). These constraints are used within the search routine (the subroutine PATS) to define the boundaries of the decision space for the problem. The search routine has built-in provisions to ensure that these constraints are not violated.

(2) The constraints imposed by the operating environment of the firm, includes:

 (a) The maximum limit on the amount of overtime as a percent of the work force level, for both types of work forces.

 (b) The maximum limit on the amount of idle time as a percent of the work force level, for both types of work forces.

 (c) The upper limit on the rate of hiring in any period, for both types of work forces.

 (d) The upper limit on the rate of employee termination during any period, for both types of work forces.

 (e) The upper limits on the levels of the month ending inventory stocks of each product line for each year in the total planning period.

 (f) The upper limits on the levels of stock shortages (expressed as a percent of sales) for each product line.

These constraints control the independent decision variables indirectly. A heavy cost penalty is charged to the objective function costs each time any restriction is exceeded. This provides a check on the activity levels of the variables. The size of the penalty cost for each constraint is determined by the value of its corresponding penalty cost factor. The values of these factors can be set anywhere between zero and one in the input data (data set-type 5). These constraints, if desired, can be made inoperative by setting the value of the corresponding penalty cost factor equal to zero. Thus, in effect, these constraints are optional.

4.3 Optimization Method

Under the SDR formulation of the aggregate production planning model the optimization function is performed through a direct computer search method using a "Pattern Search Technique". The optimization method involves defining the problem as a multi-stage decision system. A stage represents the cost structure of the firm (in the form of a cost subroutine) at a particular point in time when the decisions are to be made, which is usually, but not necessarily, monthly. The decisions for each stage are optimized with respect to overlapping n-period planning horizon. This process progresses gradually, through all the N-stages (periods/months) of the system, optimizing one stage at a time, in succession. Figure 4.2, taken from reference

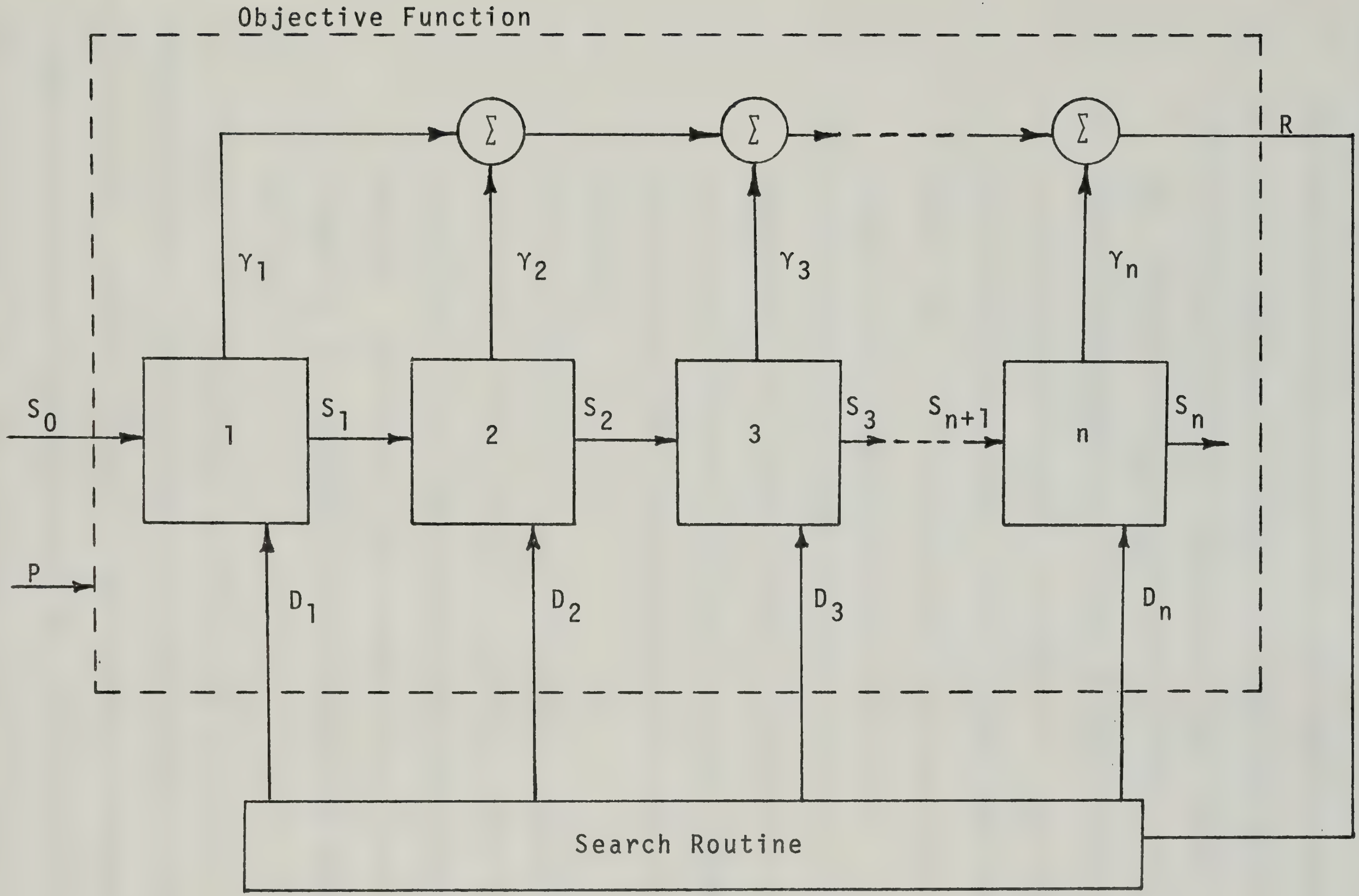


Figure 4.2: SDR Optimization Process for a Simple Multi-Stage Decision Model

[43], illustrates the complete SDR optimization process for a simple multi-stage decision model.

The notations used in Figure 4.2 are defined below:

S = a (i) component state vector, describes the state of the system at the beginning or at the end of the period of stage transformation and serves to carry information into or out of the stage-system.

P = a (k) component vector, consists of those factors which affect the stage return (γ) and the state vector (S). It contains both the demand forecasts and the production/cost parameters.

D = a (j) component vector, transmits the selected (feasible) trial values of the independent variables from the search routine to stage systems for evaluating the objective function (the stage returns).

γ = the stage return - a scaler variable, measures the utility of the stage as a single valued function of the input state, parameter and decision vectors. The sum of the returns of all the (n) stages in the planning horizon forms the criterion function.

The optimization process is iterative in nature. Each iteration involves, formulating a feasible trial solution by specifying selective values to the decision variables in the search routine and evaluating the criterion function (the stage-returns) for the planning horizon in the planning

cost subroutine. The value of the criterion function is then compared to the best previous value. If an improvement is observed the value (the trial solution) is accepted; if not it is rejected. Accordingly, the search proceeds in a systematic and sequential manner, directed by the search logic (Pattern Search) looking for better solution points in the solution space defined by the production/cost parameters. This iterative process continues, for each period/month, for a finite set of iterations and the search is terminated when the improvement observed is quite negligible, less than a specified value; or when a predetermined number of evaluations have been made.

Following the optimization of the first period/month the decisions are reviewed and implemented and a search for the optimization of the next period's decisions is started with D_2, D_3, D_4,..., D_n as the initial starting decision vectors. This process is repeated for all subsequent periods in the entire planning span. Figure 4.3, taken from reference [43], explains the information flow in the SDR monthly updating cycle. It will be observed here that the search for the first period's optimization will start with trial values (supplied as input in the data) for all the independent decision variables in the planning horizon. But, for the optimization of each subsequent period the routine needs to add trial values only for last period in the planning horizon. The demand forecast and the production/cost data will be required for the

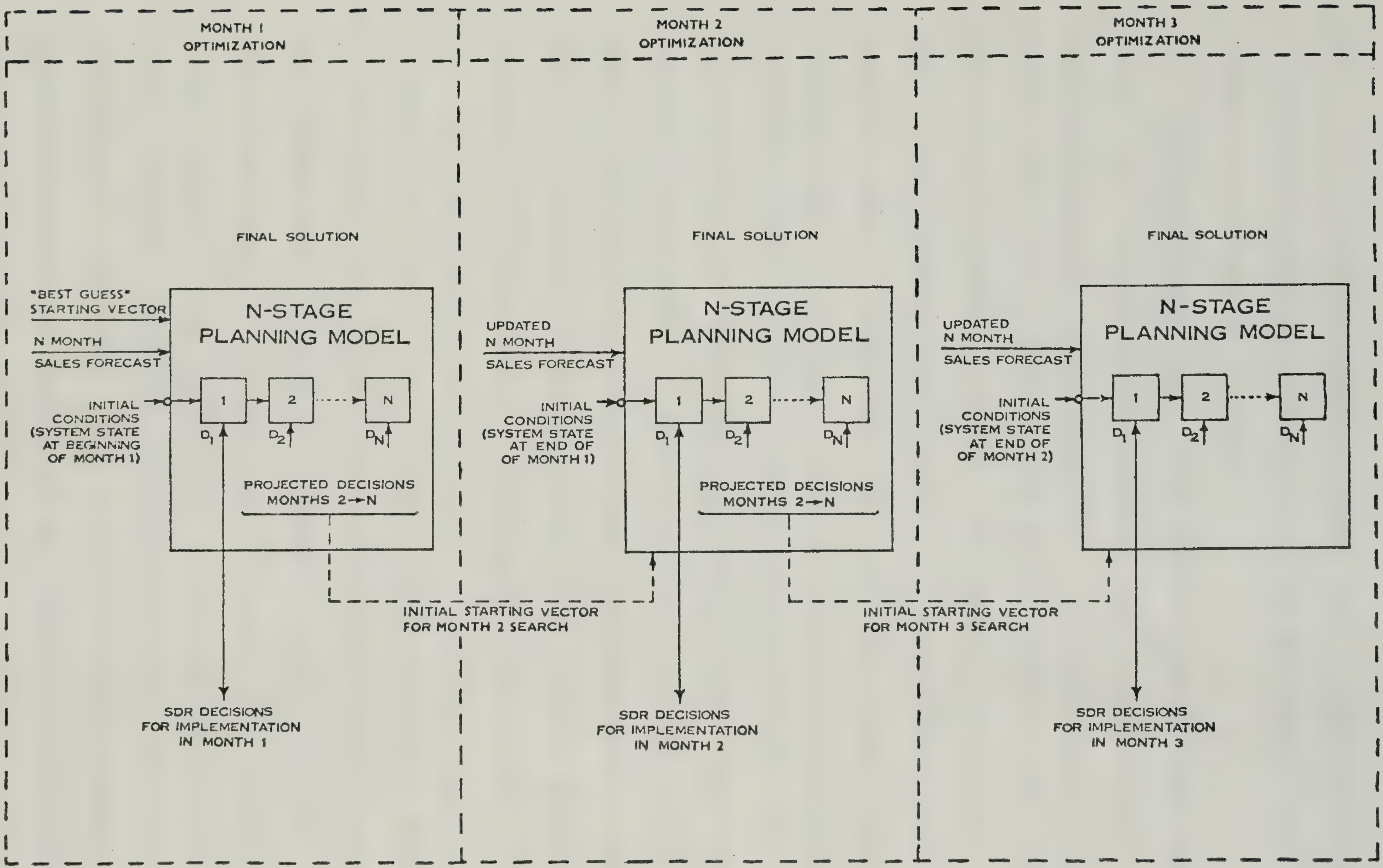
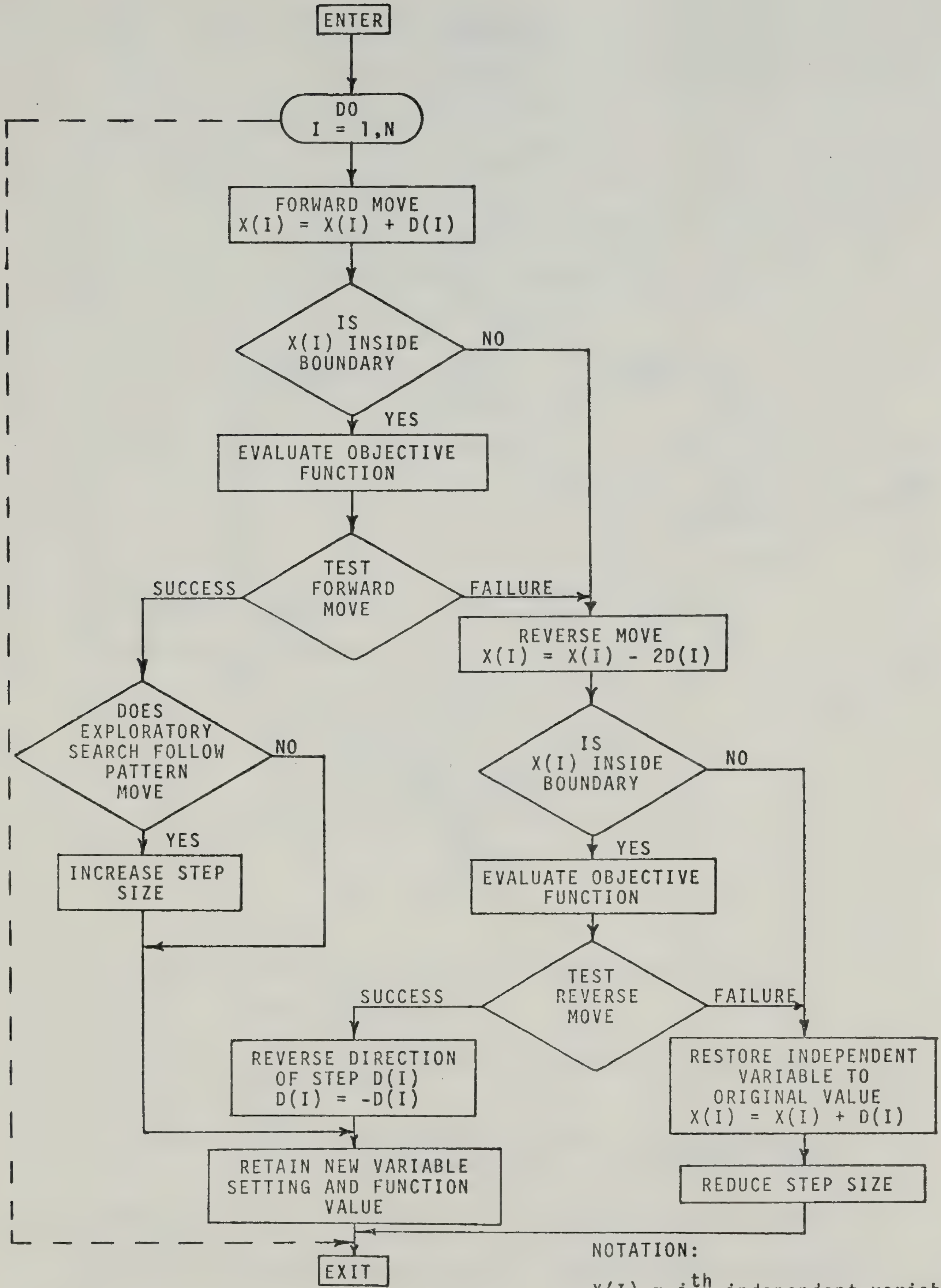


Figure 4.3: Information Flow in a Typical SDR Monthly Updating Cycle

(N + n - 1) periods, where N is the total number of periods in the entire planning span and (n) is the number of periods in a planning horizon.

Pattern Search Code. The pattern search code used in the SDR is a modified version of the original code developed by Hooke and Jeeves [23]. The strategy is completely heuristic in nature and is not based on any specific model of the response surface. The search consists of looking for better solution points in the n-dimensional decision space. A move from one point to another in the decision space is called a "pattern move" and is based, in magnitude and direction, on the information about the local characteristics of the response surface supplied by the "exploratory search". A master control strategy within the search code guides the pattern move and exploratory search logic in coordinating their actions and conducts appropriate tests for convergence and repeated pattern move failures.

The exploratory search logic is explained in detail in Figure 4.4 taken from reference [43]. Vector X contains n coordinate values of the base point and vector D contains the corresponding step sizes computed during the last exploratory search. In the search process the behavior of the function is inferred from the success or failure of the criterion function evaluations as the value of each coordinate is modified. This success/failure information is used to modify the values of the step sizes for future exploratory searches and to formulate a pattern for the

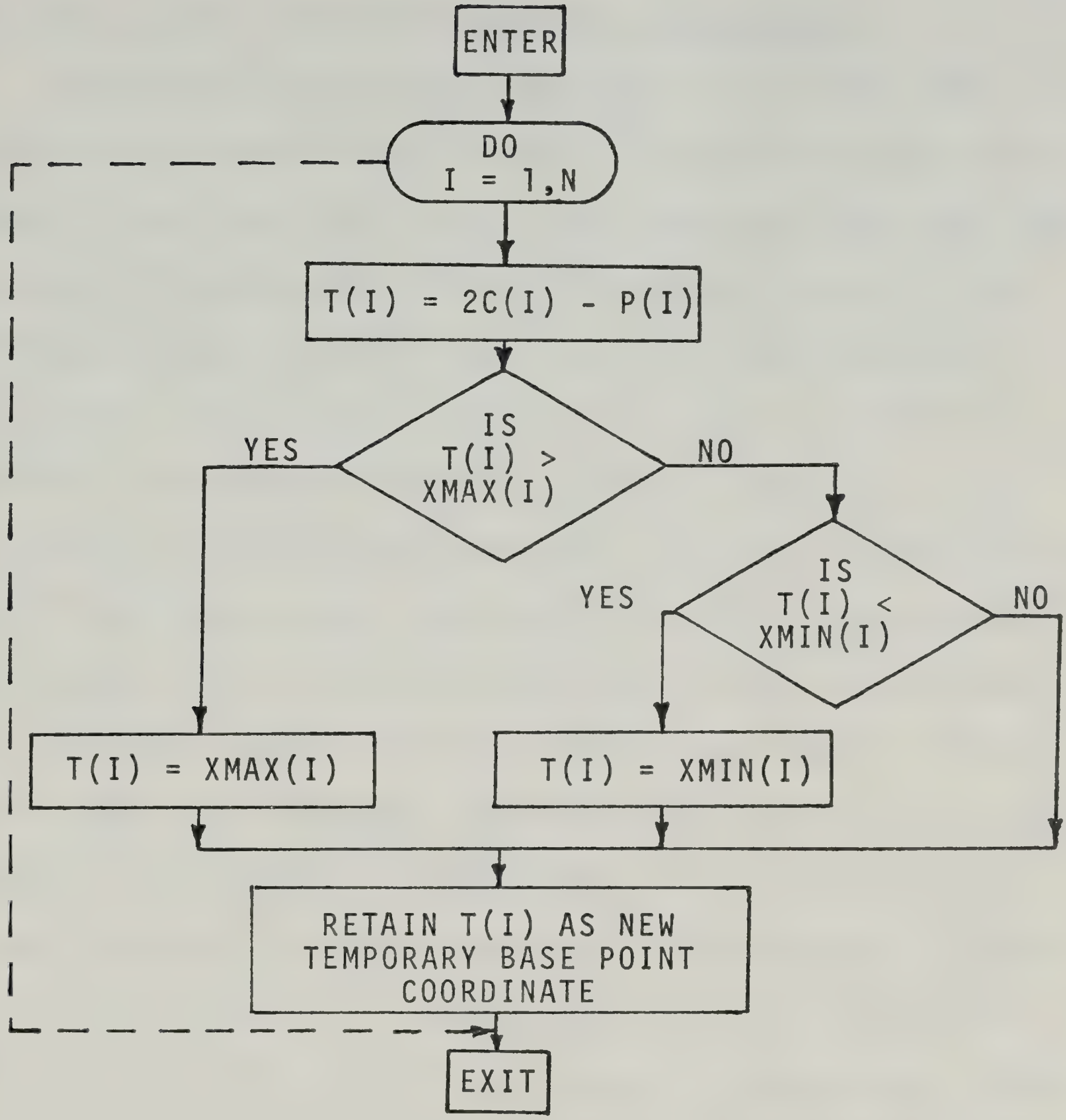


NOTATION:

X(I) = i^{th} independent variable

D(I) = step size for X(I)

Figure 4.4: Descriptive Flow Chart of the Exploratory Search Logic



C(I) = i^{th} independent variable of current base point

P(I) = i^{th} independent variable of previous base point

T(I) = i^{th} independent variable of temporary base point resulting from pattern move

XMAX(I) = upper limit of i^{th} independent variable

XMIN(I) = lower limit of i^{th} independent variable

Figure 4.5: Descriptive Flow Chart of the Pattern Move Logic

next move in the probable direction of success.

Figure 4.5, taken from reference [43], shows the details of the pattern move logic. The pattern move logic serves to move the search to a new temporary base point by changing the coordinate values by an amount equal to the difference between the new base point and the previous base point. If the local exploratory search at the new temporary base point indicates a success, the base point is accepted and the search proceeds. In case of anticipated success for future moves the built-in acceleration procedures speeds up the search process by increasing the step sizes to cover larger distances during each move. If the pattern move is a failure, the temporary base point is discarded and the pattern is destroyed. The search returns to the previous successful base point and attempts to establish a new pattern. If this fails, the step sizes are reduced and another exploratory search is conducted. This process continues until a new pattern is established and the search moves on, or the step sizes fall below a preset minimum, and the search terminates.

The Fortran version of the pattern search code, used here, has some built-in procedures for independently controlling the step size of each variable as well as some rather sophisticated search termination logic. A fully documented listing of the pattern search program is given in the Appendix.

CHAPTER 5

TESTING THE MODEL

The aggregate production planning model was tested on a hypothetical problem in order to evaluate its performance. The sample problem was designed to represent a realistic factory environment so that the results would enable one to assess the operational capabilities of the model. The problem used for testing is described in section 5.1 and the results are contained in section 5.2 of this chapter.

5.1 Sample Problem Formulation

The sample problem is a hypothetical, but nevertheless realistic model of a manufacturing firm making two lines of products in a batch production type facility. The firm presently operates two shifts but has an installed capacity for a three shift operation. The overtime is used to meet the temporary extra capacity requirements resulting from the fluctuations in sales. The company hires new employees for both the direct and indirect types of work force from two categories based upon the skill background: (1) the skilled and experienced class; and (2) semi-skilled or unskilled class. The new employees undergo a formal training program in order to familiarize themselves

with the job and improve their performance on the job.

A planning span of two years is selected with fluctuating sales demand. Decisions are made by period (each period consisting of 400 hours, 2,000 hours per year) and are expressed in terms of direct work force size, indirect work force size and production levels for both the product lines. A planning horizon of four periods is used for optimizing each period's decisions.

The input data used here for testing, listed below, is estimated to be reasonably representative of a practical situation. In the list, each (data) value is written against the corresponding variable name and in the same order as is described in Section 2.2.1.

5.1.1 Input Data

A. Master Control Data

(1)	NOY	2	(7)	JPROPX	1
(2)	NPY	5	(8)	NWI	0
(3)	NH	4	(9)	MX	3
(4)	NHM	6	(10)	KPRESS	1
(5)	JJ	2	(11)	LIM	3,000
(6)	NHP	400			

B. Data Set - Type 1

Beginning work force levels.

(1)	OWD	81

(2) OWI 58

Operating data during the period prior to the start of the plan.

(3) OED 0.95

(4) OEI 0.97

(5) OTDPI 0.10

(6) OTIPI 0.10

(7) MSO 2

C. <u>Data Set - Type 2</u>

		Product Line (1)	Product Line (2)
	Previous period's production levels (prior to the start of the plan).		
(1)	OP	433	606
	Beginning inventory levels (number of units).		
(2)	OVI	263	30
(3)	Sales forecast (number of units)		
	Period		
	1	430	700
	2	447	600
	3	440	750
	4	316	800
	5	397	890
	6	375	900
	7	292	800
	8	458	850
	9	400	900

		Period	Product Line (1)	(2)
		10	350	950
		11	284	1,000
		12	400	1,050
		13	550	1,200
		14	650	1,300
		15	600	1,250
	Limits on the levels of inventory stocks.			
(4)	VIL	Year 1	180	150
		Year 2	180	150
(5)	VIU	Year 1	400	500
		Year 2	400	500
	Other production/cost data regarding the product lines.			
(6)	ICR		0.20	0.20
(7)	PSL		0.05	0.07
(8)	CPR		12.0	5.0
(9)	CGW		10,750.0	23,150.0
(10)	P_1		0.70	0.85
(11)	P_2		0.20	0.15
(12)	P_3		0.02	0.015
(13)	TPTU		25.0	38.0
(14)	AI		3.0	6.0
(15)	CDMU		110.0	230.0

D. Data Set - Type 3

Data which is different for each year.

		Year 1	Year 2
(1)	AED	50,000.0	48,000.0
(2)	ARM	6,000.0	6,000.0
(3)	ARN	10,000.0	8,000.0
(4)	AUT	2,000.0	2,250.0
(5)	AOS	3,000.0	3,000.0
(6)	APT	10,000.0	10,000.0
(7)	ADD	5,000.0	5,000.0
(8)	ASW	2,000.0	2,000.0
(9)	ASO	4,500.0	4,500.0
(10)	AIS	70,000.0	70,000.0
(11)	COER	10.0	15.0
(12)	CPER	1.0	1.0
(13)	MDHU1	22,000.0	22,000.0
(14)	MDHU2	18,000.0	18,000.0
(15)	MDHL1	6,000.0	6,000.0
(16)	MDHL2	5,000.0	5,000.0
(17)	WI1	36	40

E. Data Set - Type 4

Data regarding the operating environment.

(1)	XI1	10	(5)	Y	5
(2)	XI3	5	(6)	Z	0.5
(3)	XI4	3	(7)	AS	0.1
(4)	X	5	(8)	AM	0.2

(9)	AP	0.2
(10)	AC	0.05
(11)	PP	0.4
(12)	PD1	0.7
(13)	PD2	0.3
(14)	EHD1	0.6
(15)	EHD2	0.10
(16)	NHTD1	200
(17)	NHTD2	900
(18)	STD1	0.1
(19)	STD2	0.3
(20)	RD	0.88
(21)	CRSD	10.0
(22)	CTFHD	1.0
(23)	PHDU	0.20
(24)	PI1	0.80
(25)	PI2	0.20
(26)	NHTI1	220
(27)	NHTI2	1,140
(28)	EHI1	0.6
(29)	EHI2	0.05
(30)	STI1	0.10
(31)	STI2	0.30
(32)	CRSI	24.0
(33)	CTFHI	1.0
(34)	PHIU	0.20
(35)	RI	0.80
(36)	PTDU	0.10
(37)	PTRU	0.03
(38)	PTIU	0.10
(39)	ES	0.22
(40)	EP	0.12
(41)	FDS	80
(42)	FDP	60
(43)	CIF	20,000.0
(44)	POTU	0.30
(45)	PUTU	0.10
(46)	ROT	1.5
(47)	PSP	1.2
(48)	PMN	0.10
(49)	CRIM	0.8
(50)	ALRD	4.5
(51)	ALRI	6.5
(52)	SD	8.0
(53)	SI	8.0
(54)	CASR	0.1
(55)	CMER	0.1
(56)	RMAR	0.2
(57)	g	0.2
(58)	PMX	1.4

F. Data Set - Type 5

Penalty cost factors.

(1)	F(1)	0.10
(2)	F(2)	0.07
(3)	F(3)	0.015
(4)	F(4)	0.010
(5)	F(5)	0.015
(6)	F(6)	0.015
(7)	F(7)	0.001
(8)	F(8)	0.002
(9)	F(9)	0.005
(10)	F(10)	0.010

G. Data Set - Type 6

Initial starting solution.

(1)	WD	103	95	98	93	90	90
(2)	WI	71	65	71	68	68	68
(3)	R(1)	348	447	441	400	400	400
	R(2)	830	620	750	750	800	800

5.2 Test Results

The aggregate production planning model was thoroughly tested using hand calculated test cases prior to actual SDR optimization. At the end of this testing phase the model was operated over a ten period planning span with the sample problem. Several test runs were made to assess the performance of the model under different operating environ-

ments. The results for a test run with the sample data are presented in Tables 5.1, 5.2, 5.3, 5.4, 5.5 and 5.6, at the end of this chapter. The operating behaviour of the model observed during the test runs led to the following conclusions:

(1) Several runs are required to obtain a satisfactory solution to the problem. Because, each time the initial starting solution is replaced with the solution from the previous run, the model results in a better solution. The values of the penalty cost factors in the input data set - type 5, also need to be reset, sometimes during each run. This is a trial and error procedure and involves increasing the values of the factors for which the corresponding constraints have been violated.

(2) the independent decision variables are quite interdependent in the criterion function cost model. Their interrelationship imposes additional (indirect) constraints, which sometimes suppresses a solution move even if it was in the right direction. This problem can be overcome by changing the values of some of the penalty cost coefficients as explained above.

(3) The quality of the solution and the speed of the optimizing process improves considerably with a reduction in the number of penalty cost constraints (listed in Section 4.2). The model has a built-in

provision of using all or none of these constraints. Therefore, one should include in the problem only those constraints that are necessary and important.

TABLE 5.1

AGGREGATE MANPOWER PLAN

Year	Period /Month	No. of Shifts	Direct Work Force Level	Indirect Work Force Level	Capacity Utilization Factor (%)
1	0	2	81	58	--
1	1	2	84	67	97.02
1	2	2	84	67	91.92
1	3	2	84	67	94.33
1	4	2	84	69	95.74
1	5	2	84	71	109.33
2	6	2	84	71	108.70
2	7	2	84	68	94.64
2	8	2	84	70	109.22
2	9	2	84	70	110.55
2	10	2	84	70	107.87

TABLE 5.2

AGGREGATE PRODUCTION PLAN

PRODUCT LINE - (1)

Year	Period /Month	Sales Forecast	Production Level	Ending Inventory Level	Ending Inventory $ Value	Stockouts (%)
1	0	---	433	263	214,393	--
1	1	430	347	180	147,359	0.00
1	2	447	519	252	201,377	0.0
1	3	440	369	180	143,630	0.00
1	4	316	317	181	143,929	0.0
1	5	397	397	180	143,051	0.00
2	6	375	372	176	161,902	0.01
2	7	292	299	182	167,638	0.0
2	8	458	457	180	165,957	0.00
2	9	400	400	180	166,020	0.00
2	10	350	282	112	103,513	0.19

TABLE 5.3

AGGREGATE PRODUCTION PLAN

PRODUCT LINE - (2)

Year	Period /Month	Sales Forecast	Production Level	Ending Inventory		Stockouts
				Level	$ Value	(%)
1	0	---	606	30	39,056	--
1	1	700	794	124	160,978	0.04
1	2	600	627	150	191,281	0.00
1	3	750	751	150	191,285	0.00
1	4	800	800	150	191,497	0.00
1	5	890	891	151	191,490	0.0
2	6	900	900	150	219,800	0.00
2	7	800	801	151	220,209	0.0
2	8	850	850	150	218,865	0.00
2	9	900	901	151	219,731	0.0
2	10	950	950	150	220,152	0.00

TABLE 5.4

WORK FORCE PERFORMANCE ANALYSIS

Year	Period /Month	Average Employee Performance Efficiency		Employee Overtime/Idle Time (%)	
		Direct Work Force	Indirect Work Force	Direct Work Force	Indirect Work Force
1	1	0.95	0.94	22.62	9.45
1	2	0.97	0.98	12.79	-0.00
1	3	1.00	1.00	12.86	0.65
1	4	1.00	0.99	14.54	0.00
1	5	1.00	0.99	30.79	8.66
2	6	1.00	1.00	30.05	7.58
2	7	1.00	1.00	13.22	-0.00
2	8	1.00	0.99	30.67	8.81
2	9	1.00	1.00	32.26	9.27
2	10	1.00	1.00	29.05	7.35

TABLE 5.5

PRODUCTION WORK FORCE COSTS

		Direct Work Force Costs					Indirect Work Force Costs				
Year	Period /Month	Regular Payroll	Overtime	Hiring/ Training	Employee Termination	Shift Premium	Regular Payroll	Overtime	Hiring/ Training	Employee Termination	Shift Premium
1	1	150,460	51,050	1,595	0	30,092	174,103	24,678	6,502	0	34,821
1	2	150,459	28,864	0	1	30,092	174,030	0	0	20	34,806
1	3	150,457	29,026	0	0	30,091	174,176	1,687	41	0	34,835
1	4	150,457	32,815	0	0	30,091	178,438	2	1,189	0	35,688
1	5	150,457	69,492	0	0	30,091	182,041	23,642	1,005	0	36,408
Total		752,290	211,247	1,595	1	150,458	882,787	50,010	8,738	20	176,557
2	6	150,457	67,818	0	0	30,091	182,315	20,728	76	0	36,463
2	7	150,457	29,833	0	0	30,091	175,837	0	0	1,807	35,167
2	8	150,457	69,218	0	0	30,091	181,664	23,997	1,626	0	36,333
2	9	150,457	72,797	0	0	30,091	181,814	25,287	42	0	36,363
2	10	150,457	65,551	0	0	30,091	181,848	20,061	10	0	36,370
Total		752,285	305,217	0	0	150,457	903,478	90,073	1,754	1,807	180,696

TABLE 5.6

TOTAL COST OF PLANT OPERATIONS

Year	Period /Month	Direct Material Costs	Direct Labour Costs	Overhead Costs	Inventory Carrying Costs	Back-Ordering Costs	Production Fluctuations Costs	Administration Costs	Marketing and Distribution Costs	Total Costs
1	1	220,559	231,602	869,435	61,366	10,768	207	139,394	139,394	1,672,725
1	2	201,106	209,414	806,647	80,292	231	243	129,793	129,793	1,557,519
1	3	213,162	209,575	828,802	67,223	23	188	131,897	131,897	1,582,767
1	4	218,737	213,363	842,877	66,958	66	73	134,207	134,207	1,610,489
1	5	248,315	250,041	954,273	66,992	223	109	151,995	151,995	1,823,943
Total		1,101,879	1,113,995	4,302,034	342,830	11,311	819	687,287	687,287	8,247,443
2	6	247,840	248,366	1,165,239	66,314	1,195	20	172,897	172,897	2,074,769
2	7	216,807	210,381	1,021,874	77,483	0	129	152,667	152,667	1,832,010
2	8	245,573	249,766	1,169,232	77,113	209	118	174,201	174,201	2,090,412
2	9	251,119	253,346	1,183,623	77,116	4	66	176,527	176,527	2,118,328
2	10	249,499	246,100	1,159,966	64,576	17,895	97	173,813	173,813	2,085,760
Total		1,210,838	1,207,959	5,699,934	362,602	19,302	430	850,107	850,107	10,201,279
									Total	18,448,721

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

The aggregate production planning system designed herein is an attempt at improving the overall effectiveness of planning in small manufacturing companies. The aim is to enable small business to be more competitive.

The aggregate production planning system, in broad terms, is a time sharing type of computer-based management system. The entire system consists of three sub-systems: (i) an information management system - which collects and prepares all the input information; (ii) an optimization system - which determines optimal planning decisions; and (iii) a planning data generating system - which develops and prints out, in specified formats, all the necessary planning information based upon the "optimal" decisions.

The computational model for the system was formulated within the framework of the SDR technique. SDR in the application is used in a similar manner to any other analytical method (e.g., Linear programming, Linear Decision Rule, etc.) for solving the operations planning problem. Under the SDR approach the problem is defined in terms of a multi-stage decision model which is then solved using a computer search technique (a direct search method for optimization). The decisions for the entire planning period

are determined stage by stage, each stage being "optimized" over a multi-period, overlapping planning horizon.

The SDR technique has certain definite advantages over other analytical methods. Unlike other methods SDR places fewer constraints on the model builder. The cost functions need not be linear or quadratic and continuous but can be in a form which seems to duplicate reality. Realistic constraints on such factors as: normal capacity, overtime, hiring and termination rates, inventories and storage capacity can be handled by the model. In other words, under SDR the model can duplicate a reasonably complete phenomenon of actual factory operations, where the optimization process involves operating the model for each decision stage to evaluate the cost impact of the period's decisions over a certain number of periods (planning horizon). This process is repeated within the search to obtain the "best" (near optimal) decisions for the period and covers the entire planning span stage by stage.

Use of this aggregate production planning system requires some background knowledge of the subroutine Pats - the search routine used in SDR. Because, with the present form of the subroutine Pats the quality of the solution and the speed of optimization depends somewhat upon the values of the step functions DEL, BET and ALP. These variables are used for search and acceleration procedures in the search routine and determine the size and nature of the step by which the value of a particular independent

variable will be incremented during the formulation of a trial solution. Therefore, it becomes somewhat mandatory to offer the system for service through some service organization where the officials can make themselves familiar with the necessary background required for using the system. This factor, as it presently exists, is a weak spot within SDR. Future study of the model will be necessary to overcome this deficiency.

The test runs with the sample problem alone are not sufficient for a complete assessment of the practical capabilities of the model. The model should be thoroughly tested in an actual factory planning situation within two or three small manufacturing companies. These tests should involve testing over some past period so as to compare the test results with actual (past) management decisions. This testing would probably reveal the areas needing improvements and modification. After necessary refinements a somewhat larger cross-section of industry should be approached and further testing of the system should be initiated. Ultimately, when fully satisfied with the performance the system may be introduced to interested companies through some central service organization.

6.1 Topics for Future Research

The aggregate production planning system can be expanded to include the following extensions in order to make the system more sophisticated and versatile.

(1) Stochastic extension. The work carried out herein is based on the deterministic, or "perfect" forecasts and cost models. A logical next step is to extend the model to a stochastic decision model to handle indeterministic forecasts and cost variables.

(2) Disaggregation extension. The aggregate production planning system, at present, handles all the production planning decision details to the extent of product lines at the overall plant level. The system can be extended to a disaggregate planning system to deal with the decision details at the level of products and departments/sections.

(3) Extension to include sensitivity analysis. The present design of the system does not have any provision for doing sensitivity analysis regarding planning decisions. This extension would include designing routines for doing the sensitivity analysis with respect to various cost parameters such as labour costs: payrolls, overtime, hiring and training costs and inventory costs.

(4) Extension for a conversational mode. Presently the system is meant for use in a batch type operating mode. It should be modified to operate in some type of conversational mode so that the user is able to interact directly with the system in his own language. By building an interactive/interrogative mode into the system it would be possible to enable the user

to establish a meaningful dialogue with the system. This addition would involve designing a special question-answer type of language.

The aggregate production planning system can be extended to develop a total corporate planning system. This would involve, developing similar planning systems for all the divisions of an industrial organization such as marketing, production, finance, engineering and development and control (purchasing, accounting, etc.). Each system can be designed and tested separately to develop a fully integrated total corporate planning system.

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APPENDIX 1

GLOSSARY OF THE VARIABLES USED IN THE COMPUTER PROGRAM

The glossary is presented, herein, in two parts. The first part covers the main routine and the subroutines FCT1, LEAEFF, OVEFF and WCOST; the second part, the subroutine PATS only.

A.1 Glossary for the Main Routine and Subroutines FCT1, LEAEFF, OVEFF and WCOST

A(I) a variable which is used for different purposes in different locations. In subroutine FCT1 it represents the amount of penalty that will be charged each time the I^{th} penalty cost constraint is violated.

In subroutine LEAEFF it is used in the computations for determining the efficiency of the new employees during the training period and appears under the name "A" in the text (refer to Section 3.1 for further details).

AA(J) a variable which is used in the subroutine LEAEFF in computing the efficiency of the new employees during the training period; appears under the name "a" in the text (refer to

Section 3.1).

ALR — a variable in subroutine WCOST which represents the average (gross) labour rate for the employees.

AMHDMX(K,Y) — the maximum production capacity of the plant that will be available through (K) number of shifts during the Y^{th} year.

B(J) — a variable which is similar to A(J); appears under the name "B" in the text (refer to Section 3.1).

BB(J) — same as above, appears under the name "b" in the text (refer to Section 3.1).

B(L,Y) — a variable name used for the variables in the data set - type 3, which represents the value of the L^{th} variable for the Y^{th} year.

C(L,J) — a variable name used for the variables (6) to (15) in the data set - type 2, represents the value of the L^{th} variable for the J^{th} product line.

CASE(NP) — the administrative expenses during the period/month (NP).

CASEK — a variable in subroutine FCT1 which means the same thing as CASE(NP).

CCP(NP) — the costs of fluctuations in the production levels during the period (NP).

CCPK — a variable in subroutine FCT1, which means the same thing as CCP(NP).

CDM(NP) — the total cost of direct materials during the period (NP).

CDMK — a variable in subroutine FCT1 which is the same as CDM(NP).

CDMT — a variable, which represents the direct material costs for any particular product line during the period (NP). This variable is used in computing the value of CDMK and OCDM.

CDW(NP) — the direct labour costs during the period (NP).

CDWH — the direct work force costs per production man-hours; used in the subroutine FCT1.

CDWK — a variable in subroutine FCT1 which means the same things as CDW(NP).

CET(M) — a variable in subroutine WCOST which represents the employee termination costs during the period (M) of the NP^{th} planning horizon.

CETD(NP) — the direct work force employee termination costs during the period (NP).

CETDK — a variable in subroutine FCT1 which means the same thing as CETD(NP).

CETI(NP) — same as CETD(NP), for the indirect work force.

CETIK — same as CETDK, for the indirect work force.

CFOH(Y) — the fixed portion of the overhead costs during the year (Y).

CHT(M) — the employee hiring and training costs during the period (M) of the NP^{th} planning horizon; used in the subroutine WCOST.

CHTA	the hiring and training cost for each employee hired; used in the subroutine WCOST.
CHTDA	the expected cost of hiring and training an employee in the direct work force.
CHTDA1	same as above, for the employees from category (a) (refer to Section 3.8).
CHTDA2	same as above, for the category (b) (refer to Section 3.8).
CHTDK	a variable which stores the values of CHTD(NP) in the subroutine FCT1 and then transfers them to the main routine.
CHTI(NP)	same as CHTD(NP), for the indirect work force.
CHTIA	same as CHTDA, for the indirect work force.
CHTIA1	same as CHTDA1, for the indirect work force.
CHTIA2	same as CHTDA1, for the indirect work force.
CHTIK	same as CHTDK, for the indirect work force.
CIC	a variable in subroutine FCT1 which is used in computing the inventory carrying costs.
CIFK	the standby costs of idle facility during any particular period; used in the subroutine FCT1.
CIMK	the total cost of indirect materials during the period (NP); used in the subroutine FCT1.
CINC(NP)	a variable in the main routine which represents the inventory carrying costs during the period (NP).
CINCK	a variable in subroutine FCT1 which means the

same as above.

CINS(NP) the inventory shortage costs during the period (NP); used in the main routine.

CINSK a variable in subroutine FCT1 which means the same thing as CINS(NP).

CINSA(J) the cost of inventory shortages per unit (short) of the product line (J).

CIS a variable in subroutine FCT1 which is used in computing the value of CINSK.

CIWK same as CDWK, for the indirect work force.

CLDO represents the direct labour costs, used in computing the manufacturing cost per unit for the period prior to the start of the plan.

CLIO same as above, for the indirect work force.

CLP(M) the regular payroll costs of the employees during the M^{th} period of the NP^{th} planning horizon; used in the subroutine WCOST.

CLPD(NP) the regular payroll costs of the direct work force during the period (NP).

CLPDK a variable in subroutine FCT1 which means the same thing as CLPD(NP).

CLPI(NP) same as CLPD(NP), for the indirect work force.

CLPIK same as CLPDK, for the indirect work force.

CME(NP) the marketing and distribution costs during the period (NP).

CMEK a variable in subroutine FCT1 which means the same as CME(NP).

COH(NP)	the overhead costs during the period (NP).
COHK	same as above, used in the subroutine FCT1.
COT(M)	the cost of employee overtime during the M^{th} period of the NP^{th} planning horizon; used in the subroutine WCOST.
COTD(NP)	the direct work force overtime costs during the period (NP).
COTDK	a variable which stores the values of COTD(NP) in the subroutine FCT1 and then transfers them to the main routine.
COTI(NP)	same as COTD(NP), for the indirect work force.
COTIK	same as COTDK, for the indirect work force.
COVI(J)	the value of the beginning inventory stock, of the product line (J), at the start of the month/period one.
CPPK	a variable in subroutine FCT1 which is used in computing the value of the objective function.
CPTH	the cost of production time per man-hour of the total work force (see Section 3.3 for a more complete explanation).
CPTK	the total production costs during the period NP; used in the subroutine FCT1.
CPUK(JC)	the manufacturing cost per unit of the product line (JC), during the period (NP); used in the subroutine FCT1.
CSPD(NP)	the shift premium costs of the direct work force during the period (NP); used in the main

	routine.
CSPI(NP)	same as above, for the indirect work force.
CSPDK	a variable in subroutine FCT1 which means the same thing as CSPD(NP).
CSPIK	same as above, for the indirect work force.
CSPO	the shift premium costs for the period prior to the start of the plan.
CSSA(I)	the coefficient for the shift start-up and shut-down cost equation which represents the value for the I^{th} year.
CSSK	the shift start-up and shut-down costs; used in the subroutine FCT1.
CUMC	a localized variable in the main routine which is used to cumulate the cost of operations for the whole plan.
CVIT(NP,J)	the value of the ending inventories for the product line (J) during the period (NP).
CVITK(JC)	a variable in subroutine FCT1 which means the same thing as CVIT(NP,J).
CW1	a variable in the subroutine OVEFF which is used in computing the overall efficiency of the work force.
DHP	the amount by which the constraint on the (percent) level of hirings in any particular period is exceeded; used in the subroutine WCOST.
DMHD	a variable in subroutine FCT1 which is used

	for computing the value of PMHD (refer to Section 3.14).
DOP	same as DHP, for overtime.
DTP	same as above, for the employee termination.
DUP	same as above, for the employee idle time.
DWD	a variable in subroutine FCT1 that measures the (absolute) amount by which the direct work force level changes during the period (NP).
DWI	same as above, for the indirect work force.
E(L)	a variable which has different meanings in different locations. In main routine and subroutine FCT1 it represents the value of the L^{th} variable of the data set - type 4. In subroutine OVEFF this variable means the average efficiency of a new employee during each period of the training program.
E(J,I)	a variable in subroutine LEAEFF which is used in computing the average efficiency of a new employee during the learning period.
EDO(NP)	the average efficiency of the direct work force employees during the period (NP).
EDOK	a variable which transfers the value of EDO(NP) from the subroutine FCT1 to the main routine.
EH(J)	the initial efficiency of the new employees, from the category (J) (refer to Section 3.6 and 3.8), at the start of the training period; used in the subroutine LEAEFF.

EH1	same as above, for the category (a).
EH2	same as above, for the category (b).
EHA	the average efficiency of the new employees during the (entire) training period; used in the subroutine LEAEFF.
EHA1	same as above, for the category (a).
EHA2	same as above, for the category (b).
EHD(I)	the expected average efficiency of a new employee during the I^{th} period of the training program.
EHDA1	the average efficiency of a new employee, hired from the category (a), during the training period (see Sections 3.6 and 3.8 for a more complete explanation).
EHDA2	same as above, for the category (b).
EHI(I)	same as EHD(I), for the indirect work force.
EHIA1	same as EHDA1, for the indirect work force.
EHIA2	same as EHDA2, for the indirect work force.
EI	the initial efficiency of the work force at the beginning of the period/month one.
EIO(NP)	same as EDO(NP), for the indirect work force.
EIOK	a variable which transfers the values of EIO(NP) from the subroutine FCT1 to the main routine.
EO(M)	the average efficiency of the work force during the M^{th} period of the planning horizon; used in the subroutines OVEFF and WCOST.

ET(I)	the expected average efficiency of a new employee during the I^{th} period of the training program; used in the subroutine LEAEFF.
F(L)	a variable which represents the value of the L^{th} variable of the data set - type 5.
FCU	the capacity utilization factor; used in the subroutine FCT1.
FCUP(NP)	the capacity utilization factor during the period (NP); used in the main routine.
FCUPK	a variable, which transfers the values of FCU from the subroutine FCT1 to the main routine.
FMD(M,J)	the man-hour equivalents of the production level of the product line (J) during the period (M) of the planning horizon; used in the subroutine FCT1.
FMDK(J)	a variable which stores the values of FMD(1,J) for future use, during the optimization of the next period; used in the subroutine FCT1.
FMHW(M)	the work force requirements, in man-hours, during the M^{th} period of the planning horizon; used in the subroutine WCOST.
FMHD(M)	the man-hour equivalents of the total direct work force requirements during the period (M) of the planning horizon; used in the subroutine FCT1.
FMHDK	a variable in subroutine FCT1 which stores the value of FMHD(1) for future use, during the

optimization of the next period.

FMHI(M)	same as FMHD(M), for the indirect work force.
FNHP	a real variable in subroutine LEAEFF which is equivalent to NHP.
HMD2	a variable in the main routine which is used in computing the coefficient for the shift start-up and shut-down costs.
HNT(J)	a variable in subroutine LEAEFF which represents the length of the training period, in hours, for the employees hired from the category (J). This variable appears under the name "NHT" in the text (refer to Sections 3.6 and 3.8 for a more complete explanation).
HNT1	same as above, for the category (a).
HNT2	same as above, for the category (b).
HW(K)	a variable in subroutine OVEFF which is used to compute the number of employees hired during the period (K).
I	a highly localized variable which is used for different purposes in different locations, mainly for indexing in the program-loops.
III	a variable which represents the maximum duration of training programs in periods (rounded to the next whole number) for the new employees from each category. This variable is used in the subroutines LEAEFF and OVEFF.
I1A	a counter that records the number of times

(in a planning horizon) the constraint for the upper limits on the levels of month-ending inventories has been violated; used in the subroutine FCT1 as a penalty cost factor.

I1B	same as above, for the lower limit on the level of inventory stocks.
I1C	a penalty cost factor for the constraint on the level of inventory shortage which is initiated at a zero value and incremented, each time the constraint is violated, by a value equal to the amount by which the constraint has been exceeded.
I1D	a multiplying factor to charge the penalty cost for violating the constraint on the (direct work force) overtime. The value of I1D is computed by summing up the percent levels by which the constraint is violated during each period of the planning horizon.
I1F	same as above, for the employee idle time.
I1G	same as above, for the rate of hiring.
I1H	same as above, for the rate of employee termination.
I2D	same as I1D, for the indirect work force.
I2F	same as I1F, for the indirect work force.
I2G	same as I1G, for the indirect work force.
I2H	same as I1H, for the indirect work force.
J	a highly localized variable which is used for

	different purposes in different locations, mainly for indexing in the program loops.
JA	a highly localized variable which represents the data set type-number in the data reading routines.
JB	same as above, for the item/variable-number within a data set.
JC	same as above, for product lines.
JD	same as above, for the year (number) corresponding to the particular data value.
JF	same as above, for the total number of variables in a data set.
JJ	the total number of product lines being manufactured.
JPROPX	an arbitrary factor used to penalize inventory deviations from a specified minimum inventory level (refer to Section 2.2.1, the master control data set, for a more complete explanation).
K	a highly localized variable, used mainly for representing the month/period in the program loops.
KFINAL	a variable, when the value is equal to one computes the required planning data based on the results of the search (for optimal decisions).
KJ	the number of independent variables in each month/period (KJ = JJ + 2).

KJ1	a highly localized variable, used as an index in some of the DO loops.
KL	same as above.
KM	the number of periods that will be considered during optimization in the SDR decision model (KM = NPY x NOY + NHM - 1).
KPRESS	a variable which, when set = 1, suppresses a large fraction of the detailed output.
KQ	a variable in subroutine WCOST and OVEFF which is used for indexing the DO loops.
KT	a variable, which is used to represent the period/month of the plan in various program loops.
KY	same as KQ.
L	a highly localized variable, used in different locations for different purposes.
LDI	same as III; used in the main routine and the subroutine FCT1 for the direct work force.
LII	same as above, for the indirect work force.
LIM	see the glossary for the subroutine PATS.
LS	a variable in subroutine WCOST which is used as an index in the program.
M	a localized variable, which is used to represent the period/month of the planning horizon in various program loops.
MS(NP)	the number of shifts the plant operates during the period (NP).

MSK	a variable which transfers the values of MS(NP) from the subroutine FCT1 to the main routine.
MSO	the number of shifts the plant operated during the period prior to the start of the plan.
MX	the maximum number of shifts the plant can operate.
M11	a (local) variable used in a DO loop.
N	the number of independent variables in the search (N = NH x KJ).
NEVAL	see glossary for the subroutine PATS.
NH	the length of the planning horizon in months/periods.
NHP	the number of regular hours of work per period/month.
NN	the length of the entire planning span in periods/months.
NOY	the length of the entire planning span in years.
NP	a counter which represents the period/stage being optimized.
NPY	the number of periods/months per year.
NT	a variable used in subroutine OVEFF as a counter.
NWI	a controlling variable whose value is either one or zero, which branches the choice of approach for estimating the indirect work force requirements in the model. Regression method is used when the value is one. Extrapolation

	is used when the value is zero.
NX18	a highly localized variable used in a DO loop.
OCDM	the direct material costs during the period prior to the start of the plan.
OCIM	same as above, for the indirect materials.
OCPU(JC)	the manufacturing cost per unit of the product line (JC) during the period prior to the start of the plan.
OCPUM	represents the maximum value among the values of OCPU(JC), JC = 1,2,3,...,JJ
OCR	a variable used in computing OCPU(JC).
OE	a variable in subroutine OVEFF which represents the average efficiency of the work force at the beginning of the period one.
OED	same as above, for the direct work force; used in the main routine and the subroutine FCT1.
OEI	same as above, for the direct work force; used in the main routine and the subroutine FCT1.
OFMD(JC)	the man-hour equivalents of the production level for the product line (JC) during the period prior to the start of the plan.
OFMHD	same as above, for the total production of all the product lines.
OP(JC)	the number of units of product line (JC) produced during the period prior to the start of the plan.
OS	a variable in subroutine OVEFF which means the

	same thing as OW.
OTDP(NP)	the level of the direct work force overtime (expressed as a fraction of the work force level) used during the period (NP).
OTIP(NP)	same as above, for the indirect work force.
OTDPI	the percent level of the direct work force overtime used during the period prior to the start of the plan.
OTIPI	same as above, for the indirect work force.
OTDPK	a variable which transfers the values of OTDP(NP) from the subroutine FCT1 to the main routine.
OTH	a variable in subroutine WCOST which is used in computing the amount of work force overtime and idle time.
OTIPK	same as OTDPK, for the indirect work force.
OTP(M)	the employee overtime (expressed as a percent of the work force level) during the M^{th} period of the planning horizon; used in the subroutine WCOST.
OVI(JC)	the beginning inventory level of the product line (JC) at the start of the period one.
OW	the work force level at the start of the period/month one; used in the subroutines WCOST and OVEFF.
OWD	same as above for the direct work force; used in the main routine and the subroutine FCT1.

OWI	same as above, for the indirect work force; used in the main routine and the subroutine FCT1.
PH(J)	a variable in subroutine LEAEFF which represents the expected proportion of the employees hired from the category (J) (refer to Section 3.8 for a more complete explanation).
PH1	same as above, for the category (a).
PH2	same as above, for the category (b).
PHTU	a variable in subroutine WCOST which represents the value of the constraint (upper limit) on the rate of hiring during any particular period. The rate of hiring is defined as the ratio of the new employees hired to the starting work force level at the beginning of the period.
PLM	a variable in subroutine WCOST which is used in computing the employee termination costs (refer to Section 3.7 for a more complete explanation).
PMHD	a variable in subroutine FCT1 which is used in computing the cost of fluctuations in production levels, appears under the name "$PMHD_t$" in the text (refer to Section 3.14).
POTU	same as PHTU, for the overtime.
PROP(M)	a vector of penalty factors used in applying the JPROPX concept (refer to Section 2.2.1,

master control variables for an explanation of JPROPX).

PROPK	a localized variable, used in computing PROP(M).
PROPL	a localized variable in subroutine FCT1, used in applying the PROP(M) function.
PTR	the maximum acceptable level of employee turnover; used in the subroutine WCOST in computing PLM (refer to Section 3.7).
PTRP	the actual average level of the employee turnover; used in the subroutine WCOST in computing PLM.
PTU	same as PHTU, for the employee terminations.
PUTU	same as above, for the employee idle time.
R(K,J)	the production level for the product line (J) during the period (K).
RA	the expected value of the learning rate constant (refer to Section 3.1).
ROT	the overtime (wage) rate premium.
S(K)	a variable in subroutine OVEFF which means the same thing as W(K).
S(K,J)	the sales forecast for the product line (J) for the period (K).
SIGMA	a dummy variable.
SJ	the value of the objective function before adding the penalty costs to it.
SN	the value of the objective function (SN = SJ +

penalty costs, see the glossary for the subroutine PATS for more details).

T(M,J) the sales forecast for the product line (J) for the M^{th} period of the NP^{th} planning horizon. This variable means the same thing as S(K,J) [T(M + NP,J) = S(K,J)].

TCOP(NP) the total cost of operations during the period (NP).

TCOPK a variable in subroutine FCT1 which means the same thing as TCOP(NP).

TCPK the value of the objective function.

TCPP the total variable production costs during the entire planning horizon.

TNK(J) a variable in subroutine LEAEFF which is used in computing E(J,K).

TNP(J) same as above.

UCP a variable in subroutine FCT1 which means the same thing as CPUK(JC) and is used in computing the inventory carrying costs.

UMHD(JD) a localized variable in the main routine which is used in computing the range for the direct work force decision vectors.

UTDP(M) the level of the direct work force idle time (expressed as a fraction of the work force level) during the period M of the planning horizon; used in the subroutine FCT1.

UTIP(M) same as above, for the indirect work force.

UTH	the amount of employee idle time in man-hours during any particular period.
UTP(M)	the level of the employee idle time expressed as a fraction of the work force level.
VI(NP,J)	the ending inventory level of the product line (J) during the period (NP).
VIK(J)	a variable which stores the values of VI(1,J) in the subroutine FCT1 and then transfers them to the main routine.
VIL(JC,Y)	the lower limit on the levels of inventory stocks of the product line (JC) during the year (Y).
VIO(J)	the inventory level of the product line (J) at the start of the period one.
VISP(NP,J)	the level of inventory shortage (expressed as a fraction of sales level) of the product line (J) during the period (NP).
VISPK	a variable in subroutine FCT1 which means the same thing as VISP(NP,J).
VIU(J,Y)	the upper limit on the level of inventory stocks of the product line (J) during the year (Y).
VS	a variable in subroutine FCT1 which computes the number of units by which the inventory level of a product line during any period is below the minimum reserve stock level.
W(K)	the work force level during the period (K);

used in the subroutines OVEFF and WCOST.

WD(NP), WI(NP)	the direct and the indirect work force levels during the period (NP).
WDMAX	the upper limit on the levels of the direct work force during any period.
WDO	a variable in subroutine FCT1; used in computing the cost of fluctuations in the production levels.
WH	a localized variable in subroutine WCOST which computes the number of employees hired during any particular period.
WO	same as above.
WHP	the level of the employees hired, expressed as a fraction of the work force level; used in the subroutine WCOST.
WIF	the indirect work force requirements (number of employees) during any particular period; used in the subroutine FCT1.
WIFI	the number of inspection and quality control employees required during any particular period; used in the subroutine FCT1.
WIMAX	same as WDMAX, for the indirect work force.
WIO	same as WDO, for the indirect work force.
WT	the number of employees terminated during any particular period; used in the subroutine WCOST.
WTP(LS)	same as WHP, for employee terminations.
X(K)	the K^{th} independent variable (see glossary for

	the subroutine PATS).
XMAX(K) XMIN(K)	the upper and lower bounds on the acceptable values of X(K).
XP	a variable in main routine, used for printing the output (final results).
XVI	same as above.
XWD	same as above.
XWI	same as above.
Z1(K) through Z10(K)	variables in main routine, used for printing out the final results.

A.2 <u>Glossary for the Subroutine PATS</u>

The material in this section is taken from reference [40].

ALP	alpha, the factor by which the step size, D(I), grows when a <u>forward</u> move is successful <u>and</u> L4 = 2. (Initialized at 2.0; used in stm 292).
BET	beta, the multiplicative factor by which step size for an independent variable is reduced if forward <u>and</u> reverse move for that variable fail.
D(I)	the current value of the step size for the I^{th} independent variable.
DEL	delta, the multiplier which is used to determine the initial value of D(I), the step size, in accordance with statement 180.

DX	a local quantity used to determine whether the lower bound on the step size has been reached. DX is computed and used only between stms 480 and 485, where step size reduction takes place.
D1	a quantity used to increment the value of GR in the adaptive logic. D1 is set in stms 802 + 1 and 804; it is used tin stm 810.
GR	the factor by which the pattern move vector is multiplied to obtain the actual size of the pattern move. (GR is initialized at 2.2 and adjusted upward, usually by increments of .1, in statements 510 through 783.) When GR reaches 3.5 it is reset to 2.2.
I	a highly localized variable used in an index in DO loops - see stms 180, 420, 786.
ID1	counter to record passes through stm 802.
ID2	counter to record passes through stm 803.
ID3	counter to record passes through stm 804.
ID4	counter to record passes through stm 801.
ITR	a printout control character of little importance; initialized at 1 and left at that value. It is tested in stm 888; if the value is > 1 it causes deletion of certain print lines. (In effect, it is not used unless initialized at ITR > 1.)
K	a subscript which defines which independent variable is now being studied -- as in X(K),

D(K), etc.

KK — a counter for one plus the number of variables studied since the last test for a new base point. When KK reaches N + 1 a test for a new base point is made. (The foregoing sentence applies when the subroutine is in the full exploratory search mode, as signified by LT $\leq$ 0 -- this is the usual mode.) KK is set equal to 1 at stms 180 + 9, 440 + 2, and 784. In the full exploratory search mode (LT $\leq$ 0) KK is incremented at 330 and tested at 330 + 1 and 404; in the truncated search mode (LT $\geq$ 1) KK is incremented at 778 and tested at 404.

KOUNT — counter of the number of times we enter the adaptive logic preparatory to attempting a pattern move. (--has same value as LT7). Incremented at stm 510 + 1.

KPRESS — a printout control character which is input on the first data card read by the main routine. KPRESS = 1 suppresses about 99% of the output generated by subroutine PATS: KPRESS = 0 allows the full details to be output during PATS.

LA — a Master Monitor of Subroutine Status which tells where to GO TO next. The primary job of LA is to control traffic through the Bound-

ary Check and the objective function subroutine. The following values of LA correspond to the following destinations:

Value of LA	Destination: Stm No.	Destination: Task
1	100	Initialization
2	282	Forward Exploratory Move - Normal
3	463	Reverse Exploratory Move - Normal (Following Fwd Failure)
4	580	Evaluate Base Point Following Pattern Move
5	285	Forward Exploratory Move - Following Pattern Move
6	466	Reverse Exploratory Move - Following Pattern Move (and Fwd Failure)
7	510	Attempt Adaptive Pattern Move
8	500	Terminate Search and Exit from Subroutine.

LIM an approximate upper bound on the number of calls of the objective function during a particular call of subroutine PATS. (LIM is usually set at 3000, but a different value might be appropriate for some applications.) See final remark under NEVAL for identification of location where NEVAL is tested.

LSN set at 0 in fifth statement of subroutine and

kept there -- never referred to again except in statement 784 + 1 (see Weisman, Wood, and Rivlin for explanation).

LT	controls the choice between the standard full exploratory search mode (LT $\leq$ 0) and the truncated search mode (LT $\geq$ 1). Under truncated mode the exploratory search is stopped as soon as <u>any</u> move produces an improvement in the last base point. This point is saved as the new base point, and a pattern move is made. The next exploratory search starts with the variable after the one which produced the last success. Under the full exploratory search mode, which is the mode this coding reflects, since LT = 0, an exploratory step is made with all N variables before a pattern move is attempted. LT is set in the fourth statement of the subroutine and does not appear again except in statements 320 and 400.
LT2	number of times this subroutine has reached status LA = 2*.
LT3	number of times this subroutine has reached status LA = 3*.
LT4	number of times this subroutine has reached status LA = 4.
LT5	number of times this subroutine has reached status LA = 5*.

LT6 number of times this subroutine has reached status LA = 6*.

LT7 number of times this subroutine has reached status LA = 7.

*in the event that a proposed forward or reverse move fails the boundary check the appropriate one of these counters will fail to be incremented.

L4 a status variable always equal to 1 or 2: L4 = 1 says we are in the process of making exploratory moves in normal fashion, i.e., we are searching for a pattern. L4 = 2 says we are in the process of making exploratory moves following a pattern move. L4 is set at stms 180 + 10, 190, 580 + 1, and (incorrectly, to no effect) at 492. It is tested at stms 290, 200, 360, 350, 779, and 492. At the time its value is output by stm 8 + 1, L4 = 1 means "the pattern move we're in the process of attempting is the first attempt in an effort to establish a new series of pattern moves." L4 = 2 means "the pattern move we're in the process of attempting has been preceeded by one or more successful pattern moves in this series."

M1 one plus the number of independent variables which have experienced both forward and reverse

failures with the minimum step size since the last test for a new base point. The search is terminated when M1 is $\geq$ N + 1 during the exploratory search mode, i.e., when L4 = 1 and we are attempting to establish a new pattern. Even though M1 may be (redundantly) manipulated while the search is conducting a post-pattern-move exploration (when L4 = 2), it is never used, i.e., tested, except when we are attempting to establish a new pattern, namely when L4 = 1. (In reprogramming, this variable could be reduced by 1, i.e., initialized to 0 and tested for $\geq$ N, with improved clarity of interpretation; this also applies to M2.) M1 is initialized in stms 180 + 6, 300 + 2, 352 + 1, and 440 + 1; incremented at 490; and tested at 429 + 1.

M2 one plus the number of independent variables which have experienced both forward and reverse failures since the last attempt to make a pattern move. The pattern is considered broken and the search is restored to exploratory mode (L4's value changes from 2 to 1) if all variables fail following a single pattern move attempt. The Wood _et al_. article and their source code says (--page 63, under M2) that the search is restored to exploratory mode

following <u>five</u> successive attempts to make a pattern move, and NPF counts these five failures. But there's a bug in their code (and Taubert's) which causes (a) NPF never to get as high as 2, and (b) the only test of NPF (stm 353) never to be reached unless a new base point has been established after a successful pattern move. Such a successful move, is <u>extremely</u> unlikely when all adjustments to the attempted pattern move have failed. The net result is that the pattern is broken after the failure of a single attempt to make a pattern move -- probably a good result <u>if</u> the test value of 5 in stm 353 is too high. In this area the source code could be condensed and clarified to an advantage, however, by modifications between stms 340 and 353, and elimination or constructive use of NPF as a variable. M2 is (redundantly) manipulated when we are in the exploratory search mode (L4 = 1), but it is never incremented or tested except when we are in the exploration-after-pattern-move-attempt mode: L4 = 2. M2 is initialized in stms 180 + 7, 300 + 1, 440, and 780; incremented at stm 493; tested at 493 + 1.

N the number of independent variables, i.e., the

	dimensionality of the space being searched.
NEVAL	a counter of the number of evaluations of FCT1, the objective function, which have been made during this particular call of subroutine PATS. NEVAL is incremented inside subroutine FCT1; it is not tested every time it is incremented. L1M is an approximate upper bound on NEVAL; the test is made in stm 7, just prior to attempting a pattern move. This is preferable to testing every time FCT1 is called.
NEVOLD	variable used to store the previous value of NEVAL, the "total number of evaluations of the objective function made thus far." NEVOLD is reset at stm 815 + 2 and is used in the computation of V in stm 398.
NPF	counter for the number of successive pattern move (attempts) which are followed by failure of all individual steps that try to adjust the pattern move attempt. (Set at 0 in stms 100 + 5, 300 + 3, 420 + 1; incremented at stms 780 + 1; tested at 353.) See discussion under M2.
OLDSN	a variable used to store a certain prior value of SN. It is initialized at stm 180 + 3, reset at stm 815, and used in the computation of V at stm 398 (within the adaptive logic).
OLDV	variable used to store the previous value of V

(reset in stm 815 + 1; used in stm 782 to compare old and new values of V).

P — a highly localized temporary storage variable used only between stms 530 + 3 and 530 + 5, where the pattern move is attempted.

Q(I) — a storage matrix for storing the old, i.e., base point, values of the independent variables. These values are initially set equal to the X(I) values and are updated in stm 530 + 4. If an attempted pattern move fails, the old values of X(I) are recovered from Q(I) in stm 420.

SC — a variable used to store the value of the objective function at the most recent base point. SC is initialized at stm 180 + 4, reset at stm 530 (just prior to attempting a pattern move), tested at statement 340 to determine whether a new base point has been established, and used to restore SP to the old value in stm 410 if the attempted pattern move fails.

SN — the value of the objective function returned by the subroutine FCT1; i.e., the cumulation of all costs over the planning horizon, using the current values of X(I) ($1 \le I \le N$) as decisions.

SNOLD — a redundant variable which is initialized at stm 180 + 2 and never referred to again for

any purpose.

SP a variable which (except in the following circumstance) is equal to the minimum value returned by the objective function thus far. The exception occurs when an exploratory search is being conducted immediately after a pattern move. In that situation SP is set (stm 580 + 2) equal to the value of the objective function which reflects the unadjusted pattern move, and thereafter, as the exploratory search to adjust the pattern move proceeds, SP is updated to reflect the minimum of this value and the best exploratory move to date. After the explorations are completed, this updated value of SP is compared (stm 340) with SC, the value of the objective function at the last base point. If this base point test is passed the (adjusted) pattern move is declared successful and a new base point is established. If the base point test is not passed the pattern move attempt is declared unsuccessful, SP is restored to its old value (stm 410), and local explorations are initiated about the old base point in an effort to establish a new pattern. (With reference to the source code, SP appears in stms 180 + 5, 280, 300, 340, 410, 460, 785, 530, and 580 + 2.)

TOL	a quantity used (stm 480 + 2) in obtaining lower bounds on step sizes for exploratory moves. (has been set at 1×10^{-5}; perhaps should be changed.) See also stm 340, where TOL is not used but perhaps should be.
V	percentage improvement in value of objective function per call of objective function. Computed and used in adaptive logic - see stms 398 through 782.
X(I)	the independent decision variables (of which there are N: $1 \leq I \leq N$). In the aggregate production planning model the vector X(I) contains the decisions for each of the (NH) months in the planning horizon. In each month the first value is the direct work force size, the second value the indirect work force size and the subsequent values are the production levels for each product line.
XMAX(I) XMIN(I)	the upper and lower bounds on the acceptable values of X(I).

APPENDIX 2

ANNOTATED LISTING OF THE COMPUTER PROGRAM, WITH SAMPLE DATA

This appendix contains a listing of the computer program developed for the aggregate production planning system. The program, written in FORTRAN IV, was run on an Amdahl 470V/6 machine at the University of Alberta Computing Services installation. A listing of the sample data, used for testing the model, is given at the end of this appendix.

```
C FORTRAN CODE FOR THE AGGREGATE PRODUCTION PLANNING MODEL,
C  SDR VERSION. PROGRAMMED IN MAY,1976 BY TEJINDER SINGH.
C  THE SEARCH ROUTINE ( SUBROUTINE PATS, BELOW) USED IN THIS
C  PROGRAM WAS TAKEN FROM REFERENCE ( 40).
C  --SEE GLOSSARY FOR THE DEFINITION  OF THE VARIABLES
C  USED IN THE PROGRAMS, BELOW.
C
C
C THE MAIN ROUTINE BEGINS HERE
C
C THIS CARD CALLS FOR DOUBLE PRECISION REAL VARIABLES
C
      IMPLICIT REAL*8 ( A-H,O-Z)
C
      DIMENSION S( 90,10 ),R( 80,10 ),VI( 80,10 ),WD( 80 ),
     1VISP( 80,10 ),CCP( 80 ),CDM( 80 ),CDW( 80 ),
     2CME( 80 ),CASE( 80 ),COH( 80 ),CETD( 80 ),WI( 80 )
     3,CETI( 80 ),CHTD( 80 ),CHTI( 80 ),CLPD( 80 ),CLPI( 80 ),
     4CINC( 80 ),CINS( 80 ),COTD( 80 ),COTI( 80 ),CSPD( 80 ),
     5CSPI( 80 ),CVIT( 80,10 ),EDO( 80 ),EIO( 80 ),OTDP( 80 ),
     6OTIP( 80 ),FCUP( 80 ),TCOP( 80 ),OP( 10 ),Z10( 6 ),
     7Z2( 6 ),Z3( 6 ),Z4( 6 ),Z5( 6 ),Z6( 6 ),Z7( 6 ),Z8( 6 ),Z9( 6 )
     8,Z1( 6 ),COVI( 10 ),UMHD( 6 ),MS( 80 )
C
      COMMON T( 12,10 ),B( 18,6 ),C( 13,10 ),E( 65 ),F( 13 ),
     1AMHDMX( 4,6 ),X( 150 ),XMAX( 150 ),XMIN( 150 ),OVI( 10 ),
     2VIL( 10,6 ),VIU( 10,6 ),EHD( 30 ),EHI( 30 ),
     3CINSA( 10 ),CSSA( 6 ),PROP( 12 ),VISPK( 10 ),
     4VIK( 10 ),SN,OFMD( 10 ),CFOH( 6 ),OCPU( 10 ),CVITK( 10 ),
     5CCPK,CDMK,CDWK,CMEK,COHK,CASEK,CETDK,CETIK,CPTH,
     6CHTDK,CHTIK,CLPDK,CLPIK,COTDK,COTIK,CINCK,CINSK,
     7CSPDK,CSPIK,TCOPK,EDOK,EIOK,OTDPK,OTIPK,OCPUM,
     8FCUPK,OFMHD,OWD,OWI,OED,OEI,CHTDA,CHTIA,SJ,SIGMA,
     9N,NP,NH,NHP,NCY,NPY,NWI,JJ,LDI,LII,LIM,MSO,MSK,
     +MX,NEVAL,KFINAL,KPRESS
C
C READ IN THE MASTER CONTROL CARD
      READ( 5,306 )NCY,NPY,NH,NHM,JJ,NHP,JPROPX,NWI,MX,KPRESS
     1,LIM
      WRITE( 6,306 )NCY,NPY,NH,NHM,JJ,NHP,JPROPX,NWI,MX,KPRESS
     1,LIM
      NN=NCY*NPY
      KM=NN+NH
      KN=NN+NHM-1
C
C READ IN THE DATA SET - TYPE 1
```

```
      READ(5,303)JA,JF
      WRITE (6,303) JA,JF
      READ (5,300) OWD,OWI,OED,OEI,OTDPI,OTIPI
      READ(5,301) MSO
      WRITE (6,500) OWD,OWI,OED,OEI,OTDPI,OTIPI
      WRITE (6,504) MSO
      JC=0
C
C READ IN THE DATA SET - TYPE 2
   10 JC=JC+1
      READ(5,303)JA,JF
      WRITE (6,503) JA,JF
      READ (5,301) OP(JC)
      READ(5,301) OVI(JC)
      WRITE (6,501) OP(JC)
      WRITE (6,501) OVI(JC)
C  SALES FORECASTS
      READ(5,300)(S(I,JC),I=1,KN)
      WRITE (6,500)(S(I,JC),I=1,KN)
C  UPPER AND LOWER LIMITS ON THE LEVELS OF
C  OF INVENTORIES FOR EACH YEAR
      IF (NOY.GT.1) GO TO 2
      READ (5,301) VIL(JC,1)
      READ (5,301) VIU(JC,1)
      WRITE (6,501) VIL(JC,1)
      WRITE (6,501) VIU(JC,1)
      GO TO 3
    2 READ (5,300) (VIL(JC,I),I=1,NOY)
      READ (5,300) (VIU(JC,I),I=1,NOY)
      WRITE (6,500) (VIL(JC,I),I=1,NOY)
      WRITE (6,500) (VIU(JC,I),I=1,NOY)
C  COST DATA WHICH IS DIFFERENT FOR EACH PRODUCT LINE
    3 JF=JF-5
      READ(5,300) (C(JB,JC),JB=1,JF)
      WRITE (6,500) (C(JB,JC),JB=1,JF)
      IF(JC.LT.JJ) GO TO 10
C
C READ IN THE DATA SET - TYPE 3
      READ(5,303) JA,JF
      WRITE (6,503) JA,JF
      DO 13 JB=1,JF
      IF (NOY.GT.1) GO TO 11
      READ (5,301) B(JB,1)
      WRITE (6,501) B(JB,1)
      GO TO 13
   11 READ (5,300) (B(JB,I),I=1,NOY)
```

```
      WRITE (6,500) (B(JB,I),I=1,NOY)
   13 CONTINUE
C
C READ IN THE DATA SET - TYPE 4
      READ(5,303) JA,JF
      WRITE (6,503) JA,JF
      READ(5,300)(E(JB),JB=1,JF)
      WRITE (6,500) (E(JB),JB=1,JF)
      E(39)=1-E(39)
      E(40)=1-E(40)
C
C READ IN THE DATA SET - TYPE 5
      READ(5,303) JA,JF
      WRITE (6,503) JA,JF
      READ(5,300)(F(JB),JB=1,JF)
      WRITE (6,500) (F(JB),JB=1,JF)
C
C READ IN THE DATA SET - TYPE 6 (THE INITIAL STARTING
C  SOLUTION)
      READ (5,303) JA,JF
      WRITE (6,303) JA,JF
      IF (NHM.GT.1) GO TO 1
      READ (5,301) WD(1)
      READ (5,301) WI(1)
      WRITE (6,501) WD(1)
      WRITE(6,501) WI(1)
      GO TO 7
    1 READ (5,300)(WD(I),I=1,NHM)
      READ (5,300) (WI(I),I=1,NHM)
      WRITE (6,500) (WD(I),I=1,NHM)
      WRITE (6,500) (WI(I),I=1,NHM)
    7 L=JJ+1
      DO 5 J=1,L
      IF (J.GT.JJ) GO TO 125
      IF (NHM.GT.1) GO TO 4
      READ (5,301) R(1,J)
      WRITE (6,501) R(1,J)
      GO TO 5
    4 READ (5,300)  (R(K,J),K=1,NHM)
      WRITE (6,500) (R(K,J),K=1,NHM)
    5 CONTINUE
C
C
C ROUTINES FOR CALCULATING THE COST COEFFICIENTS TO BE USED
C  IN THE OPTIMIZATION MODEL
C
```

```
  125 KJ=JJ+2
      N=KJ*NH
C
C CALL IN THE SUBROUTINE LEAEFF TO DETERMINE THE (WORK)
C  EFFICIENCY OF THE NEW EMPLOYEES DURING TRAINING/LEARNING
C  PERIODS
C
      CALL LEAEFF(E(20),E(16),E(17),E(14),E(15),
     1E(12),E(13),NHP,EHD,LDI,EHDA1,EHDA2)
      CALL LEAEFF(E(35),E(26),E(27),E(28),E(29),
     1E(24),E(25),NHP,EHI,LII,EHIA1,EHIA2)
      IF (KPRESS.NE.0) GO TO 70
      WRITE (6,620)
      WRITE (6,602) EHDA1,EHDA2 ,(EHD(I),I=1,LDI)
      WRITE (6,621)
      WRITE (6,602) EHIA1,EHIA2 ,(EHI(I),I=1,LII)
C
C FIXED PORTION OF THE OVERHEAD COSTS, CFOH(Y)
   70 I=0
   23 I=I+1
      CFOH(I)=B(1,I)+B(2,I)+B(3,I)+B(4,I)+
     1B(5,I)+B(6,I)+B(7,I)+B(8,I)+B(9,I)+B(10,I)
      IF (I.LT.NOY) GO TO 23
      IF (KPRESS.NE.0) GO TO 71
      WRITE (6,601)
      WRITE (6,602) (CFOH(I),I=1,NOY)
   71 OFMHD=0
C
C COST COEFFICIENT FOR THE COST OF PRODUCTIVTY LOSSES, CPTH
      CPTH =CFOH(1)/((OWD+OWI)*NHP*NPY)
C
C MANUFACTURING COST PER UNIT FOR THE PERIOD/MONTH PRIOR
C  TO THE START OF THIS PLAN
      CSPO=0
      IF (MSC.EQ.1) GO TO 16
      CSPO=NHP*(E(47)-1)*(E(50)*OWD +E(51)*OWI)
   16 CLDC=NHP*E(50)*OWD*(1+(E(46)*OTDPI))
      CLIO=NHP*E(51)*OWI*(1+(E(46)*OTIPI))
      OCDM=0.
      OCIM=0.
      JC=0
   17 JC=JC+1
      CDMT=0.
      OFMD(JC) =OP(JC)*C(8,JC)
      OFMHD=OFMHD+OFMD(JC)
      CDMT= OP(JC)*C(10,JC)
```

```
      OCDM = OCDM +CDMT
      IF(JC.LT.JJ) GO TO 17
      OCIM= E(49)*OCDM
      OCR=((CLDC+CLIC+CSPC+OCIM+(CFOH(1)/NPY))
     1/OFMHD)+B(11,1)+B(12,1)
      OCPUM=0
      JC=0
   18 JC=JC+1
      OCPU(JC)=C(10,JC)+C(8,JC)*OCR
      OCPUM= DMAX1(OCPUM,OCPU(JC))
      IF(JC.LT.JJ) GO TO 18
      IF (KPRESS.NE.0) GO TO 721
      WRITE (6,603)
      WRITE (6,602)   (OCPU(I),I=1,JJ)
      WRITE (6,605)
C
C THE TOTAL (MAX.) PRODUCTION CAPACITY OF THE PLANT
C  (INCLUDING OVERTIME) WITH EACH ADDITIONAL SHIFT,
C  AMHDMX(Q,Y)
  721 I=0
   24 I=I+1
      J=0
   28 J=J+1
      AMHDMX(J,I)=(B(13,I)+(J-1)*B(14,I))*(E(44)+1)
      IF (J.LT.MX) GO TO 28
      IF (KPRESS.NE.0) GO TO 72
      WRITE (6,606) I
      WRITE(6,602) (AMHDMX(J,I),J=1,MX)
C
C THE COEFFICIENT FOR THE SHIFT START-UP AND SHUT-DOWN
C  COST EQUATION, CSSA(Y)
   72 IF(MX.EQ.1) GO TO 119
      HMD2=E(44)*B(13,I)
      IF(HMD2.LT.B(16,I)) HMD2=B(16,I)
      IF (B(17,I).NE.0) GO TO 22
      B(17,I)=((OWI*OEI)-E(2))*B(13,I)/
     1(OWD*OED*NHF) +E(2)
   22 CSSA(I)=0
      CSSA(I)=(4.0*E(17,I)*E(11)*E(51)*(HMD2/
     1B(13,I)))+0.25*(1-E(39))*E(41)*CPTH*((HMD2
     2/NHP)+E(3))
      IF (I.LT.NOY) GO TO 24
  119 IF (KPRESS.NE.0) GO TO 29
      WRITE (6,1112)
      I=0
  120 I=I+1
```

```
      WRITE (6,1113) CSSA(I)
      IF (I.LT.NOY) GO TO 120
C
C SHORTAGES COST COEFFICIENT, CINSA(J)
   29 JC=0
   31 JC=JC+1
      CINSA(JC) = C(5,JC)*C(3,JC)+C(6,JC)*E(57)
     1*OCPU(JC)*(1+E(54)+E(55)) +C(7,JC)*C(4,JC)
      IF(JC.LT.JJ) GO TO 31
      IF (KPRESS.NE.0) GO TO 73
      WRITE(6,609)
      WRITE (6,602)(CINSA(I),I=1,JJ)
C
C HIRING AND TRAINING COST COEFFICIENTS, CHTDA AND CHTIA
   73 CHTDA1=E(21)+(E(22)+(1-EHDA1)*(CPTH+E(18)*
     1E(52)))*E(16)
      CHTDA2=E(21)+(E(22)+(1-EHDA2)*(CPTH+E(19)*
     1E(52)))*E(17)
      CHTIA1=E(32)+(E(33)+(1-EHIA1)*(CPTH+E(30)*
     1E(53)))*E(26)
      CHTIA2=E(32)+(E(33)+(1-EHIA2)*(CPTH+E(31)*
     1E(53)))*E(27)
      CHTIA=CHTIA1*E(24)+CHTIA2*E(25)
      IF (KPRESS.NE.0) GO TO 74
      WRITE (6,617) CPTH
      CHTDA=CHTDA1*E(12)+CHTDA2*E(13)
      WRITE (6,610)
      WRITE (6,1114) CHTDA,CHTIA
C
C RANGE CONSTRAINTS FOR THE INDEPENDENT VARIABLES
C  - PRODUCTION, DIRECT AND INDIRECT WORKFORCE LEVELS
   74 JC=0
   37 JC=JC+1
      XMAX(JC)=0.
      XMIN(JC)=S(1,JC)
      DO 26 I=1,KM
      XMAX(JC)=DMAX1(S(I,JC),XMAX(JC))
      XMIN(JC)=DMIN1(S(I,JC),XMIN(JC))
   26 CONTINUE
      XMAX(JC+2) =E(58)*XMAX(JC)
      XMIN(JC+2) =E(48)*XMIN(JC)
      IF(JC.LT.JJ) GO TO 37
      JD=0
   36 JD=JD+1
      UMHD(JD)=(B(13,JD)+(MX-1)*B(14,JD))/NHP
      IF(JD.LT.NOY) GO TO 36
```

```
      WDMAX=0.
      KL=NOY+1
      DO 32 I=1,KL
      IF (I.GT.NOY) GO TO 780
      WDMAX=DMAX1(UMHD(I),WDMAX)
   32 CONTINUE
  780 WDMAX=1.3*WIMAX
      WIMAX=WDMAX*(CWI/CWD)
      IF (KPRESS.NE.0) GO TO 77
      WRITE (6,614)
   77 XMAX(1)=WDMAX
      XMAX(2)=WIMAX
      XMIN(1)=0.100
      XMIN(2)=0.100
      KJ=JJ+2
      J=0
   38 J=J+1
      DO 39 I=1,KJ
      KJI=(J-1)*KJ+I
      XMAX(KJI)=XMAX(I)
      XMIN(KJI)=XMIN(I)
      IF(I-2) 150, 150, 153
  150 GO TO (151,152),I
  151 X(KJI)=WD(J)
      GO TO 39
  152 X(KJI)=WI(J)
      GO TO 39
  153 X(KJI)=R(J,I-2)
   39 CONTINUE
      IF (J.LT.NH) GO TO 38
C HERE THE VECTOR PROP(M) IS COMPUTED
      X10=NH-1
      PROPX=JPROPX
      PROPK=DLOG(PROPX)/X10
      PROPK=DEXP(PROPK)
      M11=NH+1
      DO 40 I=1,M11
      IF (I.GT.NH) GO TO 6000
      X10=I-1
   40 PROP(I)=PROPK**X10
 6000 IF (KPRESS.NE.0) GO TO 60
      DO 999 I=1,KJI
      WRITE (6,615) XMAX(I),XMIN(I),X(I)
  999 CONTINUE
C
C HERE THE PERIOD/MONTH LOOP BEGINS
```

```
   60 NP=0
   42 L=NH+1
      DO 160 M=1,L
      IF (M.GT.NH) GO TO 161
C
C ESTABLISH THE FORCAST DATA ON WHICH THE SDR OPTIMIZATION
C  FOR THIS PARTICULAR PLANNING HORIZON WILL BE BASED
      J=0
  156 J=J+1
      T(M,J)=S(NP+M,J)
      IF (J.LT.JJ) GO TO 156
  160 CONTINUE
C
C HERE NEVAL IS RESET
  161 NEVAL=0
      KFINAL=0
C CALL ADAPTIVE PATTERN SEARCH ROUTINE TO
C  OPTIMIZE OVER THIS PLANNING HORIZON.
      CALL PATS
      KFINAL=1
      CALL FCT1
C
C STORE THE RESULTS; PLANNING DATA BASED UPON THE OPTIMAL
C  DECISIONS FOR THIS PERIOD/MONTH
      NP =NP+1
      WD(NP)=X(1)
      WI(NP)=X(2)
      J=0
  162 J=J+1
      R(NP,J)=X(J+2)
      CVIT(NP,J)=CVITK(J)
      VI(NP,J)= VIK(J)
      VISP(NP,J)=VISPK(J)
      IF (J.LT.JJ) GO TO 162
      MS(NP)=MSK
      FCUP(NP)=FCUPK
      CETI(NP)=CETIK
      CHTD(NP)=CHTDK
      CCP(NP)=CCPK
      CDM(NP)=CDMK
      CDW(NP)=CDWK
      CME(NP)=CMEK
      COH(NP)=COHK
      CASE(NP)=CASEK
      CETD(NP)=CETDK
      CHTI(NP)=CHTIK
```

```
      CLPD(NP)=CLPDK
      CLPI(NP)=CLPIK
      COTD(NP)=COTDK
      COTI(NP)=COTIK
      CINC(NP)=CINCK
      CINS(NP)= CINSK
      CSPD(NP)=CSPDK
      CSPI(NP)=CSPIK
      TCOP(NP)=TCOPK
      EDO(NP)=EDOK
      EIO(NP)=EIOK
      OTDP(NP)=OTDPK
      OTIP(NP)=OTIPK
C CHECK TO SEE IF THE LAST PERIOD/MONTH IN THE
C  TIMESPAN (NN) HAS JUST BEEN COMPLETED
      IF (NP.GE.NN) GO TO 50
      IF (N.LE.KJ) GO TO 42
      NX18=N-KJ
      DO 49 I=1,NX18
   49 X(I)=X(I+KJ)
      GO TO 42
C
C
C PRINT OUT THE AGGREGATE PLANNING DECISIONS AND RELEVANT
C  INFORMATION
   50 WRITE (6,400)
      WRITE (6,419)
      WRITE (6,420)
      WRITE (6,422) MSO,OWD,OWI
      DO 43 K=1,NN
      I=(K-1)/NPY +1
      XWD=WD(K)+0.5
      XWI=WI(K)+0.5
   43 WRITE(6,421) I,K,MS(K),XWD,XWI,FCUP(K)
      J=0
   44 J=J+1
      WRITE (6,400)
      WRITE (6,401)
      COVI(J)=OVI(J)*OCPU(J)
      WRITE (6,402) J
      WRITE (6,403)
      WRITE (6,418) OP(J),OVI(J),COVI(J)
      DO 45 K=1,NN
      I=(K-1)/NPY+1
      XP=R(K,J)+0.5
      XVI=VI(K,J)+0.5
```

```
      WRITE (6,404) I,K,S(K,J),XP,XVI,CVIT(K,J),VISP(K,J)
   45 CONTINUE
      IF (J.LT.JJ) GO TO 44
      WRITE (6,400)
      WRITE (6,405)
      WRITE (6,406)
      DO 59 K=1,NN
      JD=(K-1)/NPY+1
      WRITE (6,407) JD,K,EDO(K),EIO(K),OTDP(K),OTIP(K)
   59 CONTINUE
      WRITE (6,400)
      WRITE (6,408)
      WRITE (6,410)
      J=0
   55 J=J+1
      Z1(J)=0
      Z2(J)=0
      Z3(J)=0
      Z4(J)=0
      Z5(J)=0
      Z6(J)=0
      Z7(J)=0
      Z8(J)=0
      Z9(J)=0
      Z10(J)=0
      DO 56 I=1,NPY
      K=(J-1)*NPY+I
      WRITE(6,411) J,K,CLPD(K),COTD(K),CHTD(K),
     1CETD(K),CSPD(K),CLPI(K),COTI(K),CHTI(K),
     2CETI(K),CSPI(K)
      Z1(J) = Z1(J) +CLPD(K)
      Z6(J) = Z6(J) +CLPI(K)
      Z2(J) = Z2(J) +COTD(K)
      Z7(J) = Z7(J) +COTI(K)
      Z3(J) = Z3(J) + CHTD(K)
      Z8(J) = Z8(J) + CHTI(K)
      Z4(J) = Z4(J) +CETD(K)
      Z9(J) = Z9(J) +CETI(K)
      Z5(J) = Z5(J) +CSPD(K)
   56 Z10(J) = Z10(J) +CSPI(K)
      WRITE (6,412) Z1(J),Z2(J),Z3(J),Z4(J),Z5(J),
     1Z6(J),Z7(J),Z8(J),Z9(J),Z10(J)
      IF (J.LT.NOY) GO TO 55
      WRITE (6,400)
      WRITE (6,413)
      WRITE (6,414)
```

```
      CUMC =0.
      J=0
   57 J=J+1
      Z1(J)=0
      Z2(J)=0
      Z3(J)=0
      Z4(J)=0
      Z5(J)=0
      Z6(J)=0
      Z7(J)=0
      Z8(J)=0
      Z9(J)=0

      DO 58 I=1,NPY
      K=(J-1)*NPY+I
      WRITE (6,415) J,K,CDM(K),CDW(K),COH(K),
     1CINC(K),CINS(K),CCP(K),CASE(K),CME(K),TCOP(K)
      Z2(J) = Z2(J) + CDW(K)
      Z3(J) = Z3 (J) + COH(K)
      Z1(J) = Z1 (J) + CDM(K)
      Z4(J)=Z4(J) + CINC(K)
      Z5(J)=Z5(J) + CINS(K)
      Z6(J) = Z6(J) + CCP(K)
      Z7(J)=Z7(J) + CASE(K)
      Z8(J)=Z8(J) + CME(K)
   58 Z9(J) =Z9(J)+TCOP(K)
      CUMC=CUMC+Z9(J)
      WRITE (6,416) Z1(J),Z2(J),Z3(J),Z4(J),Z5(J),
     1Z6(J),Z7(J),Z8(J),Z9(J)
      IF(J.LT.NCY) GO TO 57
      WRITE(6,417) CUMC
      WRITE(6,400)
C
  300 FORMAT(6G10.0)
  301 FORMAT(G10.0)
  303 FORMAT(2I3)
  306 FORMAT(10I5,I6)
  307 FORMAT(I6)
  500 FORMAT (6F10.3)
  501 FORMAT(F10.3)
  503 FORMAT(2I3)
  504 FORMAT(I3)
  400 FORMAT ('1')
  401 FORMAT(1X,'AGGREGATE PRODUCTION PLAN')
  402 FORMAT (//'PRODUCT LINE -',I3)
  403 FORMAT (//6X,'PERIOD',6X,'SALES',4X,
```

```
     1'PRODUCTION',6X,'ENDING INVENTORY',6X,
     2'STOCK-OUTS'/1X,'YEAR /',
     3'MONTH',4X,'FORECAST',5X,'LEVEL',8X,
     4'LEVEL',6X,'$ VALUE',6X,'(PERCENT)'//)
404 FORMAT (I4,I6,1X,4(1X,F12.0),2X,F8.2)
405 FORMAT (1X,'WORKFORCE PERFORMANCE ANALYSIS')
406 FORMAT (//21X,'AVERAGE EMPLOYEE',9X,'E',
     1'MPLOYEE OVERTIME/IDLETIME'/
     26X,'PERIOD',6X,'PERFORMANCE EFFICIENCY',
     314X,'(PERCENT)'/1X,'YE',
     4'AR',1X,'/MONTH',4X,'DIR. W.FORCE  IND. ',
     5'W.FORCE',4X,'DIR. W.FORCE  IND. W.FORCE'//)
407 FORMAT(2X,I2,3X,I3,1X,2(8X,F6.2),2X,
     12(8X,F6.2))
409 FORMAT(1X,'PRODUCTION WORKFORCE COSTS')
410 FORMAT(//12X,'( - - - - - - DIRECT  WORK',
     1'FORCE  COSTS - - - - - - )',8X,'( - - - -'
     2,' INDIRECT  WORKFORCE  COSTS - - - - )'/
     34X,'PER.',3X,'REGULAR',15X,'HIRING/',3X,
     4'EMPLOYEE',5X,'SHIFT',6X,'REGULAR',15X,
     5'HIRING/',3X,'EMPLOYEE',5X,'SHIFT'/1X,'YR',
     61X,'/MO.',3X,'PAYROLL',3X,'OVERTIME',3X,
     7'TRAINING',2X,'TERMINATION',2X,'PREMIUM',
     85X,'PAYROLL',3X,'OVERTIME',3X,'TRAINING',
     92X,'TERMINATION',2X,'PREMIUM'//)
411 FORMAT(I3,I4,1X,2(1X,5F11.0))
412 FORMAT(//' *TOTAL',1X,2(1X,5F11.0)/)
413 FORMAT (1X,'TOTAL COST OF PLANT OPERATIONS')
414 FORMAT(//15X,'DIRECT',6X,'DIRECT',16X,
     1'INVENTORY',5X,'BACK-',3X,'PRODUCTION',16X,
     2'MARKETING'/5X,'PERIOD',3X,'MATERIAL'
     3,5X,'LABOUR',5X,'OVERHEAD',4X,'CARRYING',
     43X,'ORDERING',1X,'FLUCTUATIONS',1X,'ADMINISTRA-',2X,
     5'AND DISTRI-',4X,'TOTAL'/1X,
     6'YR.',1X,'/MONTH',4X,'COSTS',7X,'COSTS',
     77X,'COSTS',7X,'COSTS',7X,'COSTS',6X,'COSTS'
     8,4X,'TION COSTS',3X,'BUTION COSTS',3X,'COSTS'//)
415 FORMAT(I3,I6,1X,9F12.0)
416 FORMAT(/' *TOTAL',3X,9F12.0/)
417 FORMAT(//94X,'**TOTAL=',F16.0)
418 FORMAT(3X,'1',5X,'0',10X,'---',1X,3(1X,F12.0),6X,
     1'---')
419 FORMAT (1X,'AGGREGATE MANPOWER PLAN')
420 FORMAT (//6X,'PERIOD  NO. OF',3X,'DIEECT W',
     1'.FORCE   INDIRECT W.FORCE   CAPACITY UTIL.'/
     21X,'YEAR /MONTH  SHIFTS',7X,'LEVEL',14X,
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     3'LEVEL',10X,'FACTOR (%)'//)
 421 FORMAT (I4,I6,I8,4X,2(F10.0,8X),2X,F8.2)
 422 FORMAT (3X,'1',5X,'0',I8,4X,2(F10.0,8X),
     16X,'---')
 601 FORMAT(//'ANNUAL FIXED OVERHEAD COSTS,CFOH(YEAR):')
 602 FORMAT (6F12.2)
 603 FORMAT(//'MFG. COST/UNIT (PROD. LINE) FOR THE PERIOD'
     1,'/MONTH PRIOR TO THE START OF THIS PLAN:'/'OCPU',
     2'(JC),JC=1,2,3...........JJ'/)
 605 FORMAT(//'TOTAL (MAX.) PLANT CAPACITY WITH EACH',
     1' ADDITIONAL SHIFT '//5X,'1 SHIFT',4X,'2 SHIFTS',4X,
     2'3 SHIFTS...............'/)
 606 FORMAT ('YEAR =',I3)
 609 FORMAT(//'SHORTAGES COST COEFF.:CINSA(JC),JC=1,2,...')
 610 FORMAT(//'HIRING.AND TRAINING COST COEFF. :',
     1//6X,'CHTDA',5X,'CHTIA'/)
1112 FORMAT(//'SHIFT START-UP AND SHUT-DOWN COST COEFF., '
     1,'CSSA(YEAR):')
1113 FORMAT (1X,F12.3)
1114 FORMAT(1X,2F10.2)
 614 FORMAT(// 9X,'XMAX',9X,'XMIN',10X,'X'/)
 615 FORMAT (3X,3F12.2)
 617 FORMAT(//'CPTH =',F12.2)
 620 FORMAT (//7X,'EHDA1',7X,'EHDA2',7X,'EHD(K).........')
 621 FORMAT (//7X,'EHIA1',7X,'EHIA2',7X,'EHI(K).........')
     STOP
     END
C
C
C
C PLANNING COST SUBROUTINE ,COMPUTES THE VALUE OF THE
C  OBJECTIVE FUNCTION AND GENERATES NECESSARY PLANNING
C  INFORMATION BASED UPON OPTIMAL DECISIONS
C
C
      SUBROUTINE FCT1
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION R(12,10),VI(10),FMD(12,10),WD(90),
     1WI(90),EDO(12),EIO(12),OTDP(12),OTIP(12),A(11),
     2FMHD(12),FMDK(10),FMHI(12),VIO(10),CPUK(10),
     3UTDP(12),UTIP(12),CLPD(12),CLPI(12),COTD(12),
     4COTI(12),CHTD(12),CHTI(12),CETD(12),CETI(12),
     5MS(12)
      COMMON T(12,10),B(18,6),C(13,10),E(65),F(13),
     1AMHDMX(4,6),X(150),XMAX(150),XMIN(150),OVI(10),
     2VIL(10,6),VIU(10,6),EHD(30),EHI(30),
```

```
     3CINSA(10),CSSA(6),PROP(12),VISPK(10),
     4VIK(10),SN,CFMD(10),CFOH(6),OCPU(10),CVITK(10),
     5CCPK,CDMK,CDWK,CMEK,COHK,CASEK,CETDK,CETIK,CPTH,
     6CHTDK,CHTIK,CLPDK,CLPIK,COTDK,COTIK,CINCK,CINSK,
     7CSPDK,CSPIK,TCOPK,EDOK,EIOK,OTDPK,OTIPK,OCPUM,
     8FCUPK,OFMHD,OWD,OWI,OED,OEI,CHTDA,CHTIA,SJ,SIGMA,
     9N,NP,NH,NHP,NCY,NPY,NWI,JJ,LDI,LII,LIM,MSO,MSK,
     +MX,NEVAL,KFINAL,KPRESS
      NEVAL=NEVAL+1
C
C LOAD PRODUCTION (R),DIRECT WORKFORCE (WD) AND INDIRECT
C  WORKFORCE (WI) DECISION VECTORS WITH TRIAL VALUES FROM
C  THE VALUES OF (X)'S SUPPLIED BY THE SEARCH ROUTINE (PATS)
      I=0
  143 I=I+1
      KJ=JJ+2
      KJI=(I-1)*KJ
      WD(NP+I)=X(KJI+1)
      WI(NP+I)=X(KJI+2)
      L=NP+I
      JC=0
  142 JC=JC+1
      R(I,JC)=X(KJI+2+JC)
      IF(JC.LT.JJ) GO TO 142
      IF (I.LT.NH) GO TO 143
C INITIALIZE THE PENALTY COST COEFFICIENTS
      I1A=0
      I1C=0
      I1D=0
      I1F=0
      I1G=0
      I1H=0
      I2D=0
      I2F=0
      I2G=0
      I2H=0
C
C SET UP THE (FIRST) PERIOD/MONTH LOOP, TO WORK OUT THE
C  WORKFORCE AND SHIFT REQUIREMENTS FOR EACH PERIOD IN
C  THE PLANNING HORIZON
      KB=NH+1
      DO 165 M=1,KB
      IF(M.GT.NH)  GO TO 56
      KT=NP+M
      FMHD(M)=0
      MS(M)=0
```

```
      JD=(KT-1)/NFY+1
      IF (JD.GT.NCY) JD=NOY
C COMPUTE THE MAN-HOUR EQUIVALENTS OF THE PRODUCTION LEVELS
      JC=0
  145 JC=JC+1
      FMD(M,JC)=R(M,JC)*C(8,JC)
      FMHD(M)=FMHD(M)+FMD(M,JC)
      IF(JC.LT.JJ) GO TO 145
C DETERMINE THE NUMBER OF SHIFTS REQUIRED
      IF(MX.EQ.1) GO TO 158
      IF(KT-1)166,166,167
  166 IF(FMHD(M).NE.OFMHD) GO TO 168
      MS(M)=MSO
      GO TO 160
  167 IF (M-1) 252,252,253
  252 IF (FMHD(M).NE.FMHDK) GO TO 168
      MS(M)=MSK
      GO TO 160
  253 IF(FMHD(M).EQ.FMHD(M-1)) GO TO 159
  168 DO 157 I=1,MX
      MS(M)=I
      IF(FMHD(M).LE.AMHDMX(I,JD)) GO TO 160
  157 CONTINUE
      GO TO 160
  158 MS(M)=1
      GO TO 160
  159 MS(M)=MS(M-1)
C DETERMINE THE INDIRECT WORKFORCE REQUIREMENTS
  160 IF(NWI.EQ.1) GO TO 162
      WIFI=0.
      JC=0
  161 JC=JC+1
      WIFI    =WIFI   +(C(9,JC)*R(M,JC)/NHP)
      IF(JC.LT.JJ) GO TO 161
      WIF=(E(7)+E(10))*WD(KT)+WIFI
     1+(E(8)+E(9))*FMHD(M)/NHP+(MS(M)-1)*E(3)
      IF(WIF.LT.E(1)) WIF=E(1)
      GO TO 55
  162 WIF=E(4)+E(5)*(WD(KT)**E(6))
   55 FMHI(M)=WIF*NHP
      IF (KFINAL.EQ.1) GO TO 56
  165 CONTINUE
C
C CALL THE SUBROUTINE OVEFF TO DETERMINE THE AVERAGE (WORK)
C  EFFICIENCY OF THE (DIRECT/INDIRECT) WORKFORCE EMPLOYEES
C
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   56 CALL OVEFF(NH,NP,OWD,WD,OED,EHD,LDI,EDO,KFINAL)
      CALL OVEFF(NH,NP,OWI,WI,OEI,EHI,LII,EIO,KFINAL)
      K=NP+1
C
C CALL THE SUBROUTINE WCOST TO DETERMINE THE WORKFORCE COSTS
C  SUCH AS : REGULAR PAYROLL, OVERTIME, HIRING AND TRAINING
C  AND EMPLOYEE TERMINATION COSTS
C
      CALL WCOST(NH,NP,NHP,E(50),WD,OWD,EDO,
     1FMHD,E(44),E(45),E(23),E(36),E(46),CHTDA,
     2E(37),OTDP,UTDP,CLPD,COTD,
     3CHTD,CETD,NPY,NOY,KFINAL,I1D,I1F,I1G,I1H)
      CALL WCOST(NH,NP,NHP,E(51),WI,OWI,EIO,
     1FMHI,E(44),E(45),E(34),E(38),E(46),CHTIA,
     2E(37),OTIP,UTIP,CLPI,COTI,
     3CHTI,CETI,NPY,NOY,KFINAL,I2D,I2F,I2G,I2H)
C
C SET UP THE SECOND PERIOD-LOOP,  TO COMPUTE THE INVENTORY
C  COSTS,THE REMAINING OPERATING COSTS,THE VALUE OF THE
C  OBJECTIVE FUNCTION AND THE PLANNING DATA
      KC=NH+1
      TCPP=0.
      DO 170 M=1,KC
      IF (M.GT.NH) GO TO 183
      KT=NP+M
      JD=((KT-1)/NPY)+1
      IF (JD.GT.NOY) JD=NOY
C INVENTORY LEVELS FOR THIS PERIOD, VI(JC)
      CINCK=0
      CINSK=0
      JC=0
  174 JC=JC+1
      UCP=0.
      CIS=0.
      CIC=0.
      VISPK(JC)=0
      IF (NP) 152,152,153
  152 UCP=OCPU(JC)
      GO TO 144
  153 UCP=CPUK(JC)
  144 IF(KT-1) 146,146,147
  146 VI(JC)=OVI(JC)+R(M,JC)-T(M,JC)
      GO TO 148
  147 IF (M-1) 250,250,251
  250 VI(JC)=VIK(JC)+R(M,JC)-T(M,JC)
      GO TO 148
```

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  251 VI(JC)=VIO(JC)+R(M,JC)-T(M,JC)
  148 VS=VI(JC)-VIL(JC,JD)
      IF(VS) 149,151,150
  149 VS=-VS
      VISPK(JC) =  VS/T(M,JC)
C CHECK FOR THE CONSTRAINTS ON INVENTORY SHORTAGES
      IF (VISPK(JC).LE.C(2,JC)) GO TO 139
      I1C=I1C+VISPK(JC)-C(2,JC)
C INVENTORY SHORTAGES COSTS
  139 CIS= VS*CINSA(JC)
      GO TO 151
  150 IF(VI(JC).GT.VIU(JC,JD)) I1A=I1A+1
C INVENTORY CARRYING COSTS. HERE TWO DIFFERENT METHODS HAVE
C  BEEN USED TO COMPUTE THE INVENTORY CARRYING COSTS: (1)
C  FOR USE IN OBJECTIVE FUNCTION ,KFINAL=0; AND (2) FOR THE
C  PURPOSE OF REPORTING THE RESULTS, KFINAL=1.
  151 IF (KFINAL.NE.1) GO TO 126
      CIC=VI(JC)*UCP*C(1,JC)
      CINCK=CINCK+CIC
      GO TO 127
C HERE IS WHERE JPROPX IS USED
  126 CIC = VS*UCP*C(1,JC)
      PROPL=PROP(M)
      IF(PROPL.EQ.1) GO TO 154
      PROPL=PROPL*(OCPUM/OCPU(JC))
  154 CIC=(PROPL-1)*C(1,JC)*UCP*VS+CIC
C CUMULATE THE INVENTORY COSTS
      CINCK =CINCK+CIC
  127 CINSK = CINSK +CIS
      IF (JC.LT.JJ) GO TO 174
C SHIFT START-UP AND SHUT-DOWN COSTS, CSSK
      CSSK=0
      IF (KT-1) 175,175,176
  175 IF (MS(M).EQ.MSO) GO TO 171
      CSSK=CSSA(JD)*IABS(MS(M)-MSO)
      GO TO 171
  176 IF (M-1) 207,207,208
  207 IF (MS(M).EQ.MSK) GO TO 171
      CSSK=CSSA(JD)*IABS(MS(M)-MSK)
      GO TO 171
  208 IF(MS(M).EQ.MS(M-1)) GO TO 171
      CSSK=CSSA(JD)*IABS(MS(M)-MS(M-1))
C COST OF FLUCTULATIONS IN PRODUCTION LEVELS (CCPK)
  171 CCPK=0
      DMHD=0
      JC=0
```

```
  172 JC=JC+1
      IF( KT-1 ) 177,177,178
  177 DMHD=DMHD+DABS( FMD( M,JC )- OFMD( JC))
      GO TO 179
  178 IF (M-1)209,209,210
  209 DMHD=DMHD+DABS( FMD( M,JC )-FMDK( JC ))
      GO TO 179
  210 DMHD=DMHD+DABS( FMD( M,JC )-FMD( M-1,JC ))
  179 IF( JC.LT.JJ ) GO TO 172
      PMHD=DMHD/FMHD( M )
      WDO=0
      WIO=0
      IF( KT-1 ) 180,180,181
  180 WDO=OWD
      WIO=OWI
      GO TO 182
  181 WDO = WD( KT-1 )
      WIO=WI( KT-1 )
  182 DWD=DABS( WD( KT )-WDO )
      DWI=DABS( WI( KT )-WIO )
      CSPIK=0
      CSPDK=0
      IF( MS( M ).EQ.1 ) GO TO 173
C SHIFT PREMIUM COSTS, CSPDK AND CSPIK
      CSPIK=( E( 47 )-1.0 )*NHP*( E( 51 )*WI( KT ))
      CSPDK=( E( 47 )-1.0 )*NHP*( E( 50 )*WD( KT ))
C STANDBY COSTS OF IDLE FACILITY
  173 CIFK =E( 43 )*UTDP( M )/NPY
      CCPK=0.5*( 0.5*( DWD+DWI )+PMHD
     1*( WDO+WIO ))*( 1-E( 40 ))*E( 42 )*CPTH+CSSK
     2+E( 51 )*E( 11 )*3.0*PMHD*WI( KT )+CIFK
C TOTAL PLANNING COSTS (VARIABLE PORTION OF THE PRODUCTION
C  COSTS)
      CPPK=CLPD( M )+CLPI( M )+COTD( M )+COTI( M )
     1+CHTD( M )+CHTI( M )+CETD( M )+CETI( M )
     2+CCPK+CINCK+CINSK+CSPDK+CSPIK
C CUMULATIVE PLANNING COSTS FOR THE PLANNING HORIZON
      TCPP=TCPP+CPPK
C THE FOLLOWING STATEMENT CAUSES A BYPASS (FOR KFINAL=0) OF
C  THE FOLLOWING (PLANNING DATA) ROUTINE DURING THE SEARCH
C  PROCESS
      IF (KFINAL.NE.1) GO TO 216
C
C
C PREPARE THE PLANNING DATA (FOR REPORTING) BASED UPON THE
C  RESULTS OF THIS STAGE'S OPTIMIZATION
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C
C CAPACITY UTILIZATICN FACTOR
      FCU=0
      FCU=FMHD(M)/(B(13,JD)+((MS(M)-1)*B(14,JD)))
      FCUPK = FCU*100.0
C DIRECT MATERIAL COSTS
      CDMK =0
      JC=0
  200 JC=JC+1
      CDMT=0.
      CDMT = R(M,JC)*C(10,JC)
      CDMK= CDMK+CDMT
      IF (JC.LT.JJ) GO TO 200
C INDIRECT MATERIAL COSTS
      CIMK = E(49)*CDMK
C DIRECT WORKFORCE COSTS
      CDWK = CLPD(M) + COTD(M) + CSPDK
C INDIRECT WORKFORCE COSTS
      CIWK = CLPI(M) + COTI(M) + CSPIK
C OVERHEAD CCSTS
      COHK = (B(11,JD) + B(12,JD))*FMHD(M)
     1+ CIWK + CIMK + CFOH(JD)/NPY
C OVERHEAD RATE (PER PRODUCTION MAN-HOUR)
      COHR = COHK/FMHD(M)
C DIRECT WORKFORCE COST PER PRODUCTION MAN-HOUR
      CDWH = CDWK/FMHD(M)
C COST OF MANUFACTURE PER UNIT
      JC=0
  204 JC=JC+1
      CPUK(JC) = C(10,JC) + C(8,JC)*(CDWH+COHR)
C VALUE OF THE ENDING INVENTORIES
      CVITK(JC)=CPUK(JC)*VI(JC)
      CVITK(JC)=DABS(CVITK(JC))
      IF (JC.LT.JJ) GO TO 204
C TOTAL COST OF PRCDUCTION
      CPTK=0.
      CPTK = CDWK+COHK+CDMK+CINCK+CINSK+CCPK
C ADMINISTRATIVE, SELLING AND MARKETING COSTS
      CMEK=CPTK*E(55)
      CASEK = CPTK*E(54)
C TOTAL COST OF OPERATIONS
      TCOPK= CPTK+CASEK+CMEK
C PREPARE REMAINING DATA FOR STRORING
      IF (OTDP(1).EQ.0) OTDP(1)=-UTDP(1)
      IF (OTIP(1).EQ.0) OTIP(1)=-UTIP(1)
      OTDPK= OTDP(1)*100.
```

```
      OTIPK= OTIP(1)*100.
      CLPDK= CLPD(1)
      CLPIK= CLPI(1)
      COTDK= COTD(1)
      COTIK= COTI(1)
      CHTDK= CHTD(1)
      CHTIK=CHTI(1)
      CETDK= CETD(1)
      CETIK= CETI(1)
      EDOK= EDO(1)
      EIOK= EIO(1)
      FMHDK=FMHD(1)
      MSK= MS(1)
      J=0
  211 J=J+1
      FMDK(J)= FMD(1,J)
      VIK(J)=VI(J)
      IF (J.LT.JJ) GO TO 211
      IF (KFINAL.EQ.1)RETURN
  216 IF (KPRESS.NE.0) GO TO 213
      WRITE (6,402) JD,KT,WD(KT),MS(M),WI(KT)
      WRITE (6,403)
      J=0
  217 J=J+1
      IF (NP) 218,218,219
  218 WRITE (6,404) J,T(M,J),R(M,J),VI(J),VISPK(J),OCPU(J)
      GO TO 220
  219 WRITE (6,404) J,T(M,J),R(M,J),VI(J),VISPK(J),CPUK(J)
  220 IF (J.LT.JJ) GO TO 217
      WRITE (6,901)
      WRITE (6,902) KT,CINCK,CINSK,CSSK,CSPDK,CSPIK,
     1CCPK,CPPK
  213 J=0
  214 J=J+1
      VIO(J)=VI(J)
      IF (J.LT.JJ) GO TO 214
  170 CONTINUE
  183 IF(NEVAL.NE.1) GO TO 117
C COMPUTE THE RATES FOR CHARGING THE PENALTY COSTS
      DO 116 I=1,10
      A(I)=TCPP*F(I)
  116 CONTINUE
C VALUE OF THE OBJECTIVE FUNCTION
  117 TCPK=TCPP+I1A*A(1)+I1C*A(2)+I1D*A(3)+I1F*A(4)
     1+I2D*A(5)+I2F*A(6)+I1G*A(7)+I2G*A(9)+I1H*A(8)
     2+I2H*A(10)
```

```
      SJ=TCPF
      SN=TCPK
  402 FORMAT (////1X,'YEAR -',I2,3X,'MONTH/PERIO'
     1,'D   :',I4,6X,'DIRECT WORKFORCE LEVEL',
     2'    :',F10.0//12X,'NO. OF SHIFTS :',I4,6X,
     3'INDIRECT WORKFORCE LEVEL :',F10.0)
  403 FORMAT (//2X,'PRODUCT-',4X,'SALES',6X,
     1'PRODUCTION',1X,'END. INVENT.',2X,
     2'STOCK-OUTS',4X,'UNIT-MFG.'/' ',3X,
     3'LINE',4X,'FORECAST',7X,'LEVEL',7X,
     4'LEVEL',7X,'(PERCENT)',6X,'COST'/)
  404 FORMAT (4X,I3,2X,3(1X,F12.0),2X,2(F8.2,6X))
  901 FORMAT (//7X,'INVENTORY',3X,'BACK',3X,'SHIFT',
     1' START-',2X,'COST OF SHIFT',1X,'COST OF',
     2'CHANG-',4X,'TOTAL'/1X,'PER.',3X,'CARRYING',
     32X,'ORDERING',1X,'UP/SHUT-DOWN',4X,'PREMIUMS',
     44X,'ING PRODUCTION',3X,'COST OF'/1X,'NO.',
     54X,'COSTS',5X,'COSTS',6X,'COSTS',4X,'D/W.F.'
     6,'    I/W.F.',4X,'LEVELS',6X,'PRODUCTION'/)
  902 FORMAT (I4,2X,6(1X,F9.0),3X,F12.0)
      RETURN
      END
C
C
C
C LEAEFF SUBROUTINE, DETERMINES THE EMPLOYEE EFFICIENCY
C  DURING LEARNING/TRAINING PERIODS
C
      SUBROUTINE LEAEFF(RA,HNT1,HNT2,EH1,EH2,
     1PH1,PH2,NHP,ET,III,EHA1,EHA2)
      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION A(2),AA(2),E(2,30),ET(1),KK(2),
     1HNT(2),TNK(2),TNP(2),EH(2),PH(2),EHA(2)
      HNT(1)=HNT1
      HNT(2)= HNT2
      EH(1)= EH1
      EH(2)= EH2
      PH(1)= PH1
      PH(2)= PH2
      FNHP=DFLOAT(NHP)
      BB=(DLOG(RA))/DLOG(2.D0)
      B=-BB/(BB+1)
      DO 1 J=1,2
      AA(J)=(BB+1)*HNT(J)*(EH(J)**(1/B))
      A(J)=(BB+1)/AA(J)
      EHA(J)=(EH(J)*(A(J)*HNT(J))**B)/(B+1)
```

```
      TNP(J)=HNT(J)/FNHP
      KK(J)=IFIX(SNGL(TNP(J)))
      IF(KK(J).LT.1) GO TO 2
      I=0
    3 I=I+1
      E(J,I)=(EH(J)*(A(J)**B)  )*((NHP*I)**(B+1)-
     1(NHP*(I-1))**(B+1))/(NHP*(B+1))
      IF (I.LT.KK(J)) GO TO 3
      IF(TNP(J).EQ.KK(J))GO TO 1
    2 TNK(J)=HNT(J)-(KK(J)*NHP)
      E(J,KK(J)+1)=((EH(J)*(A(J)**B)*((HNT(J)**
     1(B+1))-((NHP*KK(J))**(B+1)))/(B+1))+(NHP-
     2TNK(J)))/NHP
      KK(J)=KK(J)+1
    1 CONTINUE
      EHA1=EHA(1)
      EHA2=EHA(2)
      IF(KK(1).GE.KK(2))GO TO 4
      III=KK(2)
      GO TO 5
    4 III=KK(1)
    5 IF(III.GT.1) GO TO 7
      ET(1)=PH(1)*E(1,1)+PH(2)*E(2,1)
      GO TO 8
    7 DO 6 I=1,III
      IF(I.GT.KK(1))E(1,I)=1
      IF(I.GT.KK(2))E(2,I)=1
      ET(I)=PH(1)*E(1,I)+PH(2)*E(2,I)
    6 CONTINUE
    8 RETURN
      END
C
C
C
C SUBROUTINE OVEFF, DETERMINES THE AVERAGE EFFICIENCY OF
C  THE WORKFORCE
C
      SUBROUTINE OVEFF(NH,NP,OW,W,OE,E,III,EO,KFINAL)
      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION E(1),EO(1),W(1),HW(90),S(90)
      EI=OE
      J=III+NH
      OW1  =W(1)-OW
      KQ=NH+1
      DO 1 M=1,KQ
      IF (M.GT.NH) GO TO 18
```

```
      OS=OW
      HW(1)=CW1
      S(1)=W(1)
      KT=NP+M
      I=0
   25 I=I+1
      K=NP+NH+1-I
      IF (K.LE.1) GO TO 26
      HW(K)=W(K)-W(K-1)
      S(K)=W(K)
      IF (I.LE.J) GO TO 25
   26 EO(M)=0
      NT=0
      N=III+1
      DO 28 I=1,N
      IF (I.GT.III) GO TO 29
      L=1
      NT=KT+1-I
      IF (NT.LE.0) GO TO 29
      IF(HW(NT).GE.0) GO TO 10
    2 IF((NT-L).GT.0) GO TO 3
      OS=HW(NT)+OS
      HW(NT)=0
      GO TO 10
    3 IF (L.LE.(III-I)) GO TO 4
      S(NT-L)=HW(NT)+S(NT-L)
      HW(NT)=0
      GO TO 10
    4 HW(NT)=HW(NT)+HW(NT-L)
      IF(HW(NT).GE.0) GO TO 9
      HW(NT-L)=0
      L=L+1
      GO TO 2
    9 HW(NT-L)=HW(NT)
      HW(NT)=0
   10 EO(M)=EO(M)+HW(NT)*E(I)
   28 CONTINUE
   29 IF (NT-1) 30,30,31
   30 IF (KT.GT.2) EI=1.0
      IF (KT.EQ.2) EI=(1+OE)/2.
      EO(M)=(EO(M)+OS*EI)/W(KT)
      GO TO 1
   31 EO(M)=(EO(M)+S(NT-1))/W(KT)
      IF (KFINAL.EQ.1) RETURN
    1 CONTINUE
   18 RETURN
```

```
      END
C
C
C
C WCOST SUBROUTINE, DETERMINES THE WORKFORCE COSTS, EMPLOYEE
C  HIRING/TERMINATION AND OVERTIME REQUIREEMENTS
C
      SUBROUTINE WCOST( NH,NP,NHP,ALR,W,OW,EO
     1,FMHW,POTU,PUTU,PHTU,PTU,ROT,CHTA,PTRP,
     2OTP,UTP,CLP,COT,CHT,CET,NPY,NOY,
     3KFINAL,I1D,I1F,I1G,I1H)
      IMPLICIT REAL*8( A-H,O-Z )
      DIMENSION EO( 1 ),OTP( 1 ),UTP( 1 ),WTP( 30 ),
     1FMHW( 1 ),CET( 1 ),CHT( 1 ),COT( 1 ),CLP( 1 ),W( 1 )
      KQ=NH+1
      DO 60 M=1,KQ
      IF( M.GT.NH ) GO TO 65
      KT=NP+M
      LS=8+M
      JD=( ( KT-1 )/NPY )+1
      IF ( JD.GT.NOY ) JD=NOY
      WO=0
      WT=0.
      WH=0
      OTH=0
      OTP( M )=0.
      UTP( M )=0.
      UTH=0.
      WTP( LS )=0.
      COT( M )=0
      CHT( M )=0
      WHP=0
      CET( M )=0
C REGULAR PAYROLL COSTS:
      CLP( M )=ALR*W( KT )*NHP
C LEVEL OF OVERTIME/IDLETIME AND OVERTIME COSTS:
      OTH=( FMHW( M )/EO( M ))-W( KT )*NHP
      IF( OTH )52,63,53
   52 UTH=-OTH
      OTH=0
      UTP( M )=UTH/( W( KT )*NHP )
      DUP=UTP( M )-PUTU
C CHECK FOR THE WORKFORCE IDLETIME CONSTRAINTS
      IF( UTP( M ).LE.PUTU ) GO TO 63
      I1F=I1F+DUP
      GO TO 63
```

```
   53 OTP(M)=OTH/(W(KT)*NHP)
      DOP=OTP(M)-(0.75*POTU)
C CHECK FOR THE WORKFORCE OVERTIME CONSTRAINTS
      IF(OTP(M).LE.POTU) GO TO 74
      I1D=I1D+DOP
C OVERTIME COSTS
   74 COT(M)=ROT*ALR*OTH
C EMPLOYEE HIRING AND TRAINING AND TERMINATION COSTS:
   63 IF(KT-1) 61,61,62
   61 WO=OW
      GO TO 66
   62 WO=W(KT-1)
   66 WH=W(KT)-WO
      IF(WH)55,64,58
C LEVEL OF EMPLOYEE TERMINATIONS
   55 WT=-WH
      WH=0.
      WTP(LS)=WT/WO
      DTP=WTP(LS)-PTU
C CHECK FOR THE LEVEL OF EMPLOYEE TERMINATIONS
      IF (WTP(LS).LE.PTU) GO TO 59
      I1H=I1H+DTP
   59 KY=0
      PTR=0.
      DO 57 I=1,6
      IF(KT+1-I)57,57,56
   56 KY=KY+1
      PTR=PTR+WTP(LS+1-I)
   57 CONTINUE
      PTR=PTR/KY
      PLM=PTR-PTRF
      IF (PLM.LT.0) PLM=0.
C EMPLOYEE TERMINATION COSTS:
      CET(M)=CHTA*(WT+PLM *W(KT))
      GO TO 64
C EMPLOYEE HIRING AND TRAINING COSTS:
   58 WHP= WH/WC
      DHP=WHP-PHTU
C CHECK FOR THE CONSTRAINTS ON THE RATE OF HIRINGS
      IF (WHP.LE.PHTU) GO TO 67
      I1G=I1G+DHP
   67 CHT(M)=CHTA*WH
   64 IF (KFINAL.EQ.1) RETURN
   60 CONTINUE
   65 RETURN
      END
```

```
C
C
C
C
      SUBROUTINE PATS
C   PATTERN SEARCH SUBROUTINE. THIS SUBROUTINE WAS TAKEN FROM
C   T.W.SIKES'S UNPUBLISHED PH.D. DISSERTATION REFERENCE (40)
C   WHO OBTAINED IT FROM ANAND KHOKHA OF UCLA IN FEB 1970.
C                         "IT IS BASED ON THE PATTERN
C   SEARCH ROUTINES OF HOOKE-JEEVES, WEISMAN-WOOD-RIVLIN, AND
C   TAUBERT. ALTHOUGH THE SUBROUTINE CONTAINS CERTAIN
C   INEFFICIENCIES AND REDUNDANCIES (AS DOES THE MAIN
C   ROUTINE), THERE ARE NO BUGS WHICH CAUSE ERRORS.  BECAUSE
C   OF THE GREATER COMPLEXITY OF THE LOGIC, A MORE COMPLETE
C   ANNOTATION AND GLOSSARY IS PROVIDED FOR THIS SUBROUTINE.
C   THE CODE IS DIVIDED INTO 18 CONTINUOUS SUBSETS CALLED
C   BOXES, WITH ENTRANCES AND EXITS FOR EACH BOX EXHAUSTIVELY
C   IDENTIFIED.  THIS FORMS A COMPLETE BASIS FOR A FLOW
C   CHART, IF THE NEED SHOULD ARISE. THE BEST DESCRIPTION OF
C   THE PATTERN SEARCH APPEARS IN WILDE, 'OPTIMUM SEEKING
C   METHODS'. SEE ALSO REFERENCES 38 AND 35."
C
C   THE FOLLOWING STATEMENT CAUSES DOUBLE PRECISION
C   ARITHMETIC.
C
      IMPLICIT REAL*8 (A-H, O-Z)
      DIMENSION D(20),Q(20)
      COMMON T(12,10),B(18,6),C(13,10),E(65),F(13),
     1AMHDMX(4,6),X(150),XMAX(150),XMIN(150),OVI(10),
     2VIL(10,6),VIU(10,6),EHD(30),EHI(30),
     3CINSA(10),CSSA(6),PROP(12),VISPK(10),
     4VIK(10),SN,CFMD(10),CFOH(6),OCPU(10),CVITK(10),
     5CCPK,CDMK,CDWK,CMEK,COHK,CASEK,CETDK,CETIK,CPTH,
     6CHTDK,CHTIK,CLPDK,CLPIK,COTDK,COTIK,CINCK,CINSK,
     7CSPDK,CSPIK,ICOPK,EDOK,EIOK,OTDPK,OTIPK,OCPUM,
     8FCUPK,CFMHD,CWD,OWI,OED,OEI,CHTDA,CHTIA,SJ,SIGMA,
     9N,NP,NH,NHP,NCY,NPY,NWI,JJ,LDI,LII,LIM,MSO,MSK,
     +MX,NEVAL,KFINAL,KPRESS
C
C
C BOX 1,CARDS     THRU    .  PURPOSE- TO INITIALIZE DATA.
C  ENTRANCES- FROM START OF SUBROUTINE AND (DUMMY) FROM BOX
C  10 VIA STM 100. EXIT- TO 190 IN BOX 5.  COMMENT- VERY
C  STRAIGHTFORWARD.
C
  100 TOL=1.E-5
```

```
      DEL=.1
      BET=.15
      LT=0
      LSN=0
      NPF=0
      ITR=1
      ALP=2.
      GR=2.2
      LA=1
      K=1
      KV=K
      LT2=0
      LT3=0
      LT4=0
      LT5=0
      LT6=0
      LT7=0
      ID1=0
      ID2=0
      ID3=0
      ID4=0
      KOUNT=0
      V=0.
      OLDV=0.
      NEVOLD=0
      DO 180 I=1,N
      Q(I)=X(I)
C     NOTE FROM THE NEXT STATEMENT THAT THE INITIAL VALUE OF
C     D(K) DEPENDS ON HOW FAR APART THE UPPER AND LOWER
C     BOUNDARIES ARE.
C
  180 D(I)=DEL*(XMAX(I)-XMIN(I))
      CALL FCT1
      SNOLD=SN
      OLDSN=SN
      SC=SN
      SP=SN
      M1=1
      M2=1
      K=1
      KV=K
      KK=1
      L4=1
      IF (KPRESS.NE.0) GO TO 190
      WRITE(6,999) DEL,BET
  999 FORMAT('0',20X,'PATTERN SEARCH   DEL=',F6.2,' BET',
```

```
     1'=',F6.2)
      WRITE(6,991)NEVAL,KOUNT,LT2,LT3,LT4,LT5,LT6,LT7,K,KK,
     1M1,M2,NPF,LA,L4,ID1,ID2,ID3,ID4,SN,SJ, V, GR
      WRITE(6,992) KV, (D(I),I=1,N)
      GO TO 190
C
C
C BOX 18, CARDS     THRU     . PURPOSE- CALL OBJECTIVE
C  FUNCTION. ENTRANCES- FROM BOXES 17, 7, AND 14. EXITS- TC
C  STMS 100 AND 500 (DUMMY), TC 282 AND 285 IN BOX 2, TO 463
C  AND 466 IN BOX 11, AND TO 580 IN BOX 15, TO 510 IN BOX
C  13.  COMMENT- LA CONTROLS TRAFFIC THROUGH THIS BOX, SEE
C  GLOSSARY FOR INTERPRETATION OF VALUES OF LA.
C
  270 CALL FCT1
      IF (KPRESS.EQ.0)WRITE(6,993) (X(I),I=1,N)
      GO TO (100,282,463,580,285,466,510,500),LA
C
C
C BOX 2,CARDS     THRU     .  PURPOSE- TO EVALUATE A FORWARD
C  MOVE. ENTRANCE- FROM BOX 18 VIA STMS 282, 285.  EXITS- TO
C  360 IN BOX 6 WHEN FWD MOVE FAILS, TO 300 IN BOX 3 WHEN
C  FWD MOVE SUCCEEDS.  COMMENT- WE REACH THIS BOX WHEN LA=2
C  OR 5. -- FIRST INCREMENT STATE COUNTER--
C
  282 LT2=LT2+1
      GO TO 280
  285 LT5=LT5+1
C  -- THEN TEST FOR SUCCESS (290) OR FAILURE (360)
C
  280 IF(SN-SP)290,360,360
  290 GO TO (300,292),L4
C  -- NEXT IF WE ARE IN AN EXPLCRATORY MODE FOLLOWING A
C  PATTERN MOVE (ATTEMPT), WE MULTIPLY THIS SUCCESSFUL
C  FORWARD STEP SIZE BY ALP.
C
  292 D(K)=D(K)*ALP
C
C
C BOX 3, CARDS     THRU     .  PURPOSE - TO RESET SOME
C  VARIABLES ENTRANCES- FROM BCXES 2 AND 11, BOTH VIA STM
C  300.  EXIT- TO 305 IN BOX 4   COMMENT- STRAIGHTFORWARD --
C  SEE GLCSSARY FOR DEFINITIONS.
C
  300 SP=SN
      M2=1
```

```
      M1=1
      NPF=0
C
C
C BOX 4, CARDS      THRU     .  PURPOSE - TO DECIDE WHETHER
C  TO TEST FOR A NEW BASE POINT. ENTRANCE- FROM BOXES 3 AND
C  12 VIA STN 305.  EXITS- TO 340 IN BOX 7 WHEN A BASE POINT
C  TEST IS REQUIRED, -TO 200 IN BOX 5 OTHERWISE.  COMMENT-
C  THIS BOX IS THE ONLY ENTRANCE TO THE BASE POINT TEST, BOX
C  7. ALSO NOTE THAT WHEN LT=0, AS IT NORMALLY IS (SEE
C  GLOSSARY), IT IS ONLY HERE THAT KK IS INCREMENTED AND
C  TESTED.
C
  305 K=K+1
      IF(K-N)320,320,777
  777 K=1
  320 IF(LT)330,330,340
  330 KK=KK+1
      IF(KK-N)200,200,340
C
C
C BOX 5, CARDS      THRU     .  PURPOSE - SET SOME INDICES
C  AND INCREMENT THE VALUE OF X(K) IN PREPARATION FOR
C  TESTING A FORWARD MOVE IN THE K TH VARIABLE.  ENTRANCES-
C  FROM BOX 1 VIA STM 190, BOXES 4 AND 8 VIA STM 200, BOX 10
C  VIA STM 190, BOX 15 VIA STM 210.  EXITS- TO 490 IN BOX 12
C  WHEN VARIABLE IS FIXED AND CANNOT BE PETURBED, TO 230 IN
C  BOX 17 (BOUNDARY CHECK) OTHERWISE.  COMMENT- HERE WE
C  ADJUST X(K) TO TRY A FORWARD MOVE.
C
  200 GO TO (190,210),L4
  190 L4=1
      LA=2
      GO TO 220
  210 LA=5
C  HERE'S WHERE WE CHECK FOR VARIABLES WHICH ARE FIXED.
C
  220 IF(D(K))225,490,225
  225 X(K)=X(K)+D(K)
      GO TO 230
C
C
C BOX 6, CARDS     THRU    .  PURPOSE- WHEN FWD MOVE FAILS WE
C  REACH BOX 6 AND SET THE VALUE OF X(K) IN PREPARATION FOR
C  ATTEMPTING A REVERSE MOVE.  ENTRANCES- FROM BOXED 2 AND
C  17, BOTH VIA STN 360. EXIT- TO 230 IN BOX 17 (BOUNDARY
```

```
C  CHECK) ALWAYS.  STMS 360 THROUGH 380 SHOULD BE 'SET, THEN
C  TESTED AND RESET IF NECESSARY' WHEN REPROGRAMMING FOR
C  SPEED.
C
  360 GO TO (370,380),L4
  370 LA=3
      GO TO 390
  380 LA=6
  390 X(K)=X(K)-2*D(K)
      GO TO 230
C
C
C BOX 17, CARDS   THRU   . PURPOSE-BOUNDARY CHECK IN
C  PREPARATION FOR POSITIVE OR NEGATIVE MOVE OF X(K).
C  ENTRANCE- FROM BOXES 5 AND 6 VIA STM 230. EXITS- TO 270
C  IN BOX 18 (FCT1) WHEN BOUNDARY CHECK IS PASSED, TO 500
C  (DUMMY) IN CERTAIN EVENTS WHEN FAILED, TO 360 IN BOX 6
C  WHEN POSITIVE MOVE FAILS THE BOUNDARY CHECK, TO 480 IN
C  BOX 2 WHEN NEGATIVE MOVE FAILS THE BOUNDARY CHECK.
C  COMMENT- 270 IMPLIES BOUNDARY WAS NOT VIOLATED.
C
  230 IF(X(K)-XMAX(K))250,270,260
  250 IF(XMIN(K)-X(K))270,270,260
  260 GO TO (500,360,480,500,360,480,500,500),LA
C
C
C BOX 7,CARDS   THRU   . PURPOSE-TEST TO SEE WHETHER A NEW
C  BASE POINT HAS BEEN ESTABLISHED. ENTRANCE- FROM BOX 4 VIA
C  STM 340. EXITS - TO 400 IN BOX 8 WHEN TEST FOR NEW BASE
C  POINT FAILS, TO 270 IN BOX 18 (FCT1) WHEN NEW BASE POINT
C  IS ESTABLISHED. COMMENT- FIRST, NOTE THE TOLERANCE OF
C  .0001 IN STM 340-- IS THIS THE BEST VALUE-. NEXT, SEE
C  NOTE UNDER M2 AND NPF IN GLOSSARY. ONE TROUBLE WITH THE
C  EXISTING CODE IS THAT IN STM 340 '400,400' COULD BE
C  '353,353' AND/OR '5' IN STM 353 IS TOO HIGH. LOOK INTO
C  THIS SOMETIME. FOR EXAMPLE, IF IT IS DESIRABLE TO LET NPF
C  GROW ABOVE 1, SUCCESSIVE PATTERN MOVE ATTEMPTS (BEFORE
C  THIS PATTERN IS DECLARED BROKEN) MIGHT TRY INCREASING THE
C  D(K) AND/OR DECREASING THE VALUE OF GR. IN ANY CASE NPF
C  PROBABLY SHOULD ALWAYS BE LESS THAN 3 OF 4. AS THE CODE
C  NOW STANDS STMS 350 AND 353 ARE REDUNDANT -- THE BRANCH
C  FROM STM 340 TO 350 COULD LEAD DIRECTLY TO STM 352
C  INSTEAD, SINCE UNDER THE CODE'S EXISTING LOGIC NPF CANNOT
C  BECOME GREATER THAN 1.
C
  340 IF(SP+.0001-SC)350,400,400
```

```
C  350 MEANS WE HAVE SUCCESSFULLY IDENTIFIED A NEW BASE
C  POINT. IF L4=1 WE SHOULD NOW ATTEMPT THE FIRST PATTERN
C  MOVE IN THIS SERIES.
C
  350 GO TO (352,353),L4
  352 LA=7
      M1=1
      GO TO 270
  353 IF(NPF-5)352,400,400
C
C
C BOX 8,CARDS   THRU   . PURPOSE- HAVING FAILED TO
C  ESTABLISH A NEW BASE POINT, WE REACH THIS BOX TO DECIDE
C  WHERE TO GO NEXT. ENTRANCE- FROM BOX 7 VIA STM 400.
C  EXITS- TO 200 IN BOX 5 WHEN KK.LE.N AFTER BASE POINT TEST
C  (-IMPOSSIBLE WITH LT=0),TO 410 IN BOX 9 WHEN FAILURE
C  OCCURS AT THE CONCLUSION OF ADJUSTMENTS FOLLOWING AN
C  ATTEMPTED PATTERN MOVE, TO 440 IN BOX 10 WHEN IN THE
C  PROCESS OF SEARCHING FOR A NEW PATTERN AND THE VALUE OF
C  M1 (SEE GLOSSARY) IS LESS THAN N+1, TO 500 IN BOX 16 WHEN
C  NO NEW PATTERN IS FOUND (SEE N1 IN GLOSSARY) AND SEARCH
C  IS TO BE TERMINATED. COMMENT- CONCERNING STMS 770 AND
C  404, SEE FINAL SENTENCE UNDER KK IN GLOSSARY. STM 420 IS
C  REDUNDANT, BUT THE STM NUMBER IS NOT.
C
  400 IF(LT)404,404,778
  778 KK=KK+1
  404 IF(KK-N)200,200,779
  779 GO TO (429,410),L4
  429 L4=2
      IF(M1-N)440,440,500
C
C
C BOX 9,CARDS   THRU   . PURPOSE- RESTORE THE VALUES OF
C  X(I), AFTER UNSUCCESSFUL ATTEMPT TO ESTABLISH NEW BASE
C  POINT.  ENTRANCE- FROM BOX 8 VIA STM 410.  EXIT- TO 440
C  IN BOX 10.
C
C
  410 SP=SC
      DO 420 I=1,N
  420 X(I)=Q(I)
      NPF=0
C
C
C BOX 10, CARDS   THRU   . PURPOSE- TO RESET SOME
```

```
C  COUNTERS-- SEE GLOSSARY FOR DEFINITIONS. ENTRANCE- FROM
C  BOXES 8 AND 9, BOTH VIA STM 440. EXIT- TO 190 IN BOX 5.
C
  440 M2=1
      M1=1
      KK=1
      GO TO 190
C
C
C BOX 11, CARDS   THRU   . PURPOSE- TO EVALUATE A REVERSE
C  MOVE- (CORRESPONDS TO BOX 2'S FWD MOVE EVALUATION).
C  ENTRANCE- FROM BOX 18 (FCT1) VIA STMS 463,446. EXITS TO
C  480 IN BOX 12 WHEN REVERSE MOVE FAILS, TO 300 IN BOX 3
C  WHEN REVERSE MOVE SUCCEEDS. COMMENT- NOTE THAT AS USUAL
C  WE SET THE COUNTERS LT3 AND LT6, DEPENDING ON WHETHER WE
C  REACHED THIS BOX WITH LA=3 OR 6.
C
  463 LT3=LT3+1
      GO TO 460
  466 LT6=LT6+1
  460 IF(SN-SP)470,480,480
C  SUCCESS-- THEREFORE IN THE FUTURE A FORWARD MOVE WILL BE
C  WHAT HAS HERETOFORE BEEN A BACKWARD MOVE-- HENCE, STM 470
C
  470 D(K)=-D(K)
      GO TO 300
C BOX 12, CARDS   THRU   . PURPOSE- AFTER REVERSE MOVE
C  FAILURE THIS BOX REDUCES STEP SIZE AND ATTEMPTS TO TRY AN
C  EXPLORATORY STEP FOR ANOTHER VARIABLE. ENTRANCES- FROM
C  BOX 5 VIA STM 490, FROM BOXES 17 AND 11, BOTH VIA STMS
C  480.  EXIT- TO 305 IN BOX 4.
C
  480 X(K)=X(K)+D(K)
      D(K)=D(K)*BET
C  OBSERVE THIS USE OF THE VARIABLE TOL.  WHEN REPROGRAMMIN-
C  G, THE DOUBLE PRECISION ABSOLUTE VALUE FUNCTION SHOULD BE
C  REPLACED WITH A COUPLE OF EASY FORTRAN STATEMENTS.
C
      DX= DABS(X(K)/D(K)*TOL)
      IF(1-DX)481,482,484
  481 D(K)=D(K)*DX
C  HOW WAS '1.E-30' SELECTED?  IS IT OPTIMAL WITHIN A FACTOR
C  OF 1000?
C
  482 DX= DABS(1.E-30/D(K))
      IF(1-DX)483,490,490
```

```
  483 D(K)=D(K)*DX
      GO TO 490
  484 DX= DABS(1.E-30/D(K))
      IF(1-DX)485,490,492
C  WITH THIS SCHEME IT WOULD SEEM THAT D(K) MIGHT OSCILLATE,
C  BUT FURTHER EMPIRICAL STUDY IS NEEDED HERE. IT IS WORTH
C  OBSERVING THAT D(K) IS RARELY AND MODESTLY INCREASED, BUT
C  ( IN THIS BOX) SHARPLY- BET= .1- DECREASED.
C
  485 D(K)=D(K)*DX
  490 M1=M1+1
C  IN STM 492 THE TRANSFER TO '495' TRANSFERS CONTROL TO STM
C  305 VIA THE LONG WAY AROUND. IT SHOULD BE MORE DIRECT.
C
  492 GO TO (495,493),L4
  495 GO TO 309
  493 M2=M2+1
      IF(M2-N)309,309,780
  780 M2=1
      NPF=NPF+1
  309 GO TO 305
C
C
C BOX 13, CARDS   THRU   . PURPOSE- ADAPTIVE LOGIC TO
C  COMPUTE GR, A MULTIPLICATIVE FACTOR THAT GOVERNS THE SIZE
C  OF THE PATTERN MOVE ATTEMPT.  ENTRANCE- FROM BOX 18(FCT1)
C  VIA STM 510. EXIT- TO 883 IN BOX 14.  COMMENT- BY
C  OBSERVING THE OUTPUT FROM PATS IN THE HMMS MODEL, IT IS
C  SEEN THAT 99 % OF THE TIME GR SIMPLY GROWS BY INCREMENTS
C  OF .1 FROM 2.2 TO 3.5 --THEN IS RESET TO 2.2 FOR ANOTHER
C  CYCLE.  THE ADAPTIVE LOGIC SEEMS TO OFFER GREAT
C  OPPORTUNITIES FOR IMPROVEMENT.  NOTE, AMONG OTHER
C  THINGS, THAT IS AN EXISTING PATTERN IS BROKEN A NEW ONE
C  IS FOUND (IF POSSIBLE) BUT GR IS NOT RESET TO 2.2.  ALSO,
C  SOMETHING SHOULD BE ADDED TO THE PRINTED OUTPUT OF THIS
C  SUBROUTINE TO MARK WHEN AND UNDER WHAT CIRCUMSTANCES AN
C  EXISTING PATTERN IS BROKEN AND ANOTHER ONE FOUND.
C
  510 LT7=LT7+1
      KOUNT=KOUNT+1
C  THIS FUNCTION 'MOD' IS ALWAYS EQUAL TO ZERO IN THIS CODE,
C  SINCE THE SECOND ARGUMENT ALWAYS EQUALS 1.  THIS IS A
C  FUNCTION WHICH SHOULD BE REDESIGNED TO SERVE A PURPOSE,
C  OR BETTER YET, ELIMINATED ALTOGETHER.
C
      IF(MOD(KOUNT,1))888,398,888
```

```
  398 V=(OLDSN-SN )*100/(OLDSN*(NEVAL-NEVOLD))
      IF(.6-V)801,781,781
  781 IF(V-.3)802,782,782
  782 IF(OLDV-V)803,804,804
  801 ID4=ID4+1
      GO TO 815
  802 ID1=ID1+1
      D1=.1
      GO TO 810
  803 ID2=ID2+1
      GO TO 815
  804 ID3=ID3+1
      D1=.05
  810 GR=GR+D1
      IF(GR-3.5)815,783,783
  783 GR=2.2
  815 OLDSN=SN
      OLDV=V
      NEVOLD=NEVAL
C
C
C BOX 14, CARDS   THRU   . PURPOSE-- SET X(1) TO MAKE
C  PATTERN MOVE ATTEMPT. ENTRANCE- FROM BOX 13 VIA STM 888.
C  EXITS- TO 270 IN BOX 18 (FCT1) ALMOST ALWAYS, TO 500 IN
C  BOX 16 WHEN NEVAL VIOLATES LIMIT CAUSING A RETURN TO MAIN
C  ROUTINE. COMMENT- NOTE THAT A BOUNDARY CHECK IS CONTAINED
C  IN THIS BOX AND IS SLIGHTLY DIFFERENT FROM THE BOUNDARY
C  CHECK IN BOX 17 INSOFAR AS THE CONSEQUENCES OF FAILING
C  THE CHECK ARE CONCERNED.  ALSO NOTE THAT SINCE ITR=1 THIS
C  MOD FUNCTION IN STM 888 PERFORMS NO USEFUL PRINTOUT
C  CONTROL SERVICE.  IT SHOULD BE REMOVED.
C
  888 IF(MOD(KOUNT,ITR))7,8,7
    8 IF (KPRESS.NE.0) GO TO 7
      WRITE(6,991 )NEVAL,KOUNT,LT2,LT3,LT4,LT5,LT6,LT7,K,KK,
     1M1,M2,NPF,LA,L4,ID1,ID2,ID3,ID4,SN,SJ, V, GR
      WRITE(6,992 ) KV, (D(I),I=1,N)
    7 IF(LIM-NEVAL )500,784,784
  784 KK=1
      IF(LSN )530,530,785
  785 SP=SN
  530 SC=SP
      LA=4
      DO 570 I=1,N
      P=Q(I)
      Q(I)=X(I)
```

```
      X(I)=P+GR*(X(I)-P)
      IF(X(I)-XMAX(I))550,570,786
  786 X(I)=XMAX(I)
      GO TO 570
  550 IF(XMIN(I)-X(I))570,570,787
  787 X(I)=XMIN(I)
  570 CONTINUE
      GO TO 270
C
C
C BOX 15, CARDS   THRU   . PURPOSE- RESET CERTAIN COUNTERS
C  (SEE GLOSSARY) PRIOR TO BEGINNING ADJUSTMENTS OF THE
C  PATTERN MOVE ATTEMPT. ENTRANCE- FROM BOX 18 (FCT1) VIA
C  STM 580.  EXIT- TO 210 IN BOX 5 ALWAYS.
C
C
  580 LT4=LT4+1
      L4=2
      SP=SN
      GO TO 210
C
C
C BOX 16, CARDS   THRU   . PURPOSE- TO PRINT OUT FINAL
C  PARAMETER VALUES AND TERMINATE THE SEARCH.  ENTRANCE-
C  FROM BOXES 17 AND 18 (DUMY), FROM BOXES 8 AND 14, ALL VIA
C  STM 500.  EXIT- (RETURN TO MAIN ROUTINE ALWAYS)
C
  500 LA=8
  990 WRITE(6,7538)
 7538 FORMAT (1H0)
      WRITE(6,991)NEVAL,KOUNT,LT2,LT3,LT4,LT5,LT6,LT7,K,KK,
     1M1,M2,NPF,LA,L4,ID1,ID2,ID3,ID4,SN,SJ, V, GR
      WRITE(6,992) KV, (D(I),I=1,N)
  991 FORMAT (1H ,I5, 4I4, 1X, 3I4, 4I3, 3I2, 1X, 4I3,
     12F14.4,F8.5,F5.2)
  992 FORMAT(I3,16F7.3)
  993 FORMAT(3X,16F6.0)
      RETURN
      END
```

SAMPLE DATA DECK

```
* - 1ST COLUMN
    2     5     4     6     2  400     1     0     3     1  3000
  1  7
    81.0       58.0        0.95       0.97        .10        .10
         2
  2 15
   433.0
   263.0
   430.0      447.0      440.0      316.0      397.0      375.0
   292.0      458.0      400.0      350.0      284.0      400.0
   550.0      650.0      600.0
   180.0      180.0
   400.0      400.0
      .20        .05       12.0    10750.0        .70        .20
      .02       25.0        3.0      110.0
  2 15
   606.0
    30.0
   700.0      600.0      750.0      800.0      890.0     900.00
   800.0      850.0      900.0      950.0     1000.0    1050.00
  1200.0     1300.0     1250.0
   150.0      150.0
   500.0      500.0
      .20        .07        5.0    23150.0        .85        .15
      .015      38.0        6.0      230.0
  3 17
 50000.0    48000.00
  6000.0     6000.0
 10000.0     8000.0
  2000.0     2250.0
  3000.0     3000.0
 10000.0    10000.0
  5000.0     5000.0
  2000.0     2000.0
  4500.0     4500.0
 70000.0    70000.0
    10.        15.0
     1.0        1.0
 22.00E 03  22.00E 03
 18.00E 03  18.00E 03
  6000.0     6000.0
  5000.0     5000.0
    36.0       40.0
  4 58
    10.0        5.0        3.0        5.0        5.0        0.5
```

```
      .10        .20        .20        .05        .40        .70
      .30        .60        .10      200.0      900.00       .10
      .30        .88      10.0        1.0        .20        .80
      .20      220.0    1140.0        .60        .05        .10
      .30       24.0       1.0        .20        .80        .10
      .03        .10        .22        .12      80.00      60.00
 20000.          .30        .10       1.5        1.2        .10
      .8        4.5        6.5        8.0        8.0        .10
      .10        .20        .2        1.4
 5 10
      .10        .07        .015       .010       .015       .015
      .001       .002       .005       .010
 6  3
  103.0       85.0       98.0       93.0       90.0       90.0
   71.0       65.0       71.0       68.0       68.0       68.0
  348.0      447.0      441.0      400.0      400.0      400.0
  830.0      620.0      750.0      750.0      800.0      800.0
```

(END OF SAMPLE DATA DECK)

APPENDIX 3

REGRESSION MODEL SUBROUTINE

The regression model subroutine computes the values of the coefficients (X, Y and Z) of the regression equation ($WI^* = X + Y(WD)^Z$) to be used in estimating the indirect work force requirements within the aggregate production planning model (refer to Section 3.5 for complete details). The computer program, written for this subroutine in FORTRAN IV, was successfully run on an Amdahl 470V/6 installation at the University of Alberta Computing Services. The input data requirements for using this subroutine are as given below.

Input Data. One requires to furnish the following information in the input data:

(1) The minimum level (X) of the indirect work force required to maintain the plant (operations) at a zero direct work force level.

(2) The historical data about the direct work force levels (WD) the corresponding indirect work force levels (WI) during the past periods/months.

(3) The number (N) equal to the number of the data sets (the values of WD and WI both) included in the input data.

Data Deck. All data cards follow the same general

format as shown below:

	Field 1	Field 2
Columns	1-10	11-20
Numeric Values		

All numeric values appearing on the data cards must be integer numbers and should be placed (punched), within the respective fields as far to the right as possible. Each data card is explained in detail below:

(1) The first data card will have the number N in the field one.

(2) The second data card will have the value of (X) in the field one.

(3) The third and each subsequent card will have the values of (WI) and (WD) in the fields one and two respectively.

A listing of the computer program for the regression model subroutine is given on the following page.

```
C   SUBROUTINE FOR DEVELOPING THE REGRESSION EQUATION FOR
C   FORECASTING THE INDIRECT WORKFORCE REQUIREMENTS
      IMPLICIT REAL*8 (A-H,O-Z)
      SP=0
      SQ=0
      SQS=0
      SPQ=0
      READ (5,51) N
      READ (5,51)I
      R=I
      DO 1 L=1,N
      READ (5,52) J,K
      P=J-I
      Q=K
      P=DLOG(P)
      Q=DLOG(Q)
      SP=SP+P
      SQ=SQ+Q
      SPQ=SPQ+(P*Q/N)
    1 SQS=SQS+(Q**2)/N
      SPA=SP/N
      SQA=SQ/N
      SSQ=SQA**2
      B=(SPQ-(SPA*SQA))/(SQS-SSQ)
      A=SPA-(B*SQA)
      A=DEXP(A)
      WRITE (6,53) R,A,B
   51 FORMAT(I10)
   52 FORMAT(2I10)
   53 FORMAT(5X,'X=',F12.5,'  Y=',F12.5,'  Z=',F12.5)
      STOP
      END
```

APPENDIX 4

METHOD FOR ESTIMATING THE EFFECTIVE LEARNING RATE CONSTANT FOR THE COMBINED PLANT-OPERATIONS

The method, presented herein, for estimating the effective learning rate constant for use in the aggregate production planning model is an application of the correlation curve for the learning curve ratios developed by Titleman [45]. This correlation curve (shown in the Figure A4.1) is based on the empirical data and defines the relationship between the job learning rate constants and the manual ratios (the proportion of the manual elements involved in an operation) for the manufacturing operations. For any measured manual ratio this curve gives the value of the learning rate constant within a maximum error of 2.5 percent. The effective learning rate constant for the combined plant-operations can be determined in the following manner:

First list all the individual operations and determine the proportion that each operation occupies in the total available production man-hours. Then multiply the manual ratio of each operation by its proportion of the total production man-hours. This gives a weighted manual ratio for each operation. The sum total of these weighted

manual ratios gives the effective manual ratio for the combined plant-operations. This effective manual ratio can now be used to read corresponding effective learning rate constants from the correlation curve (Figure A4.1).

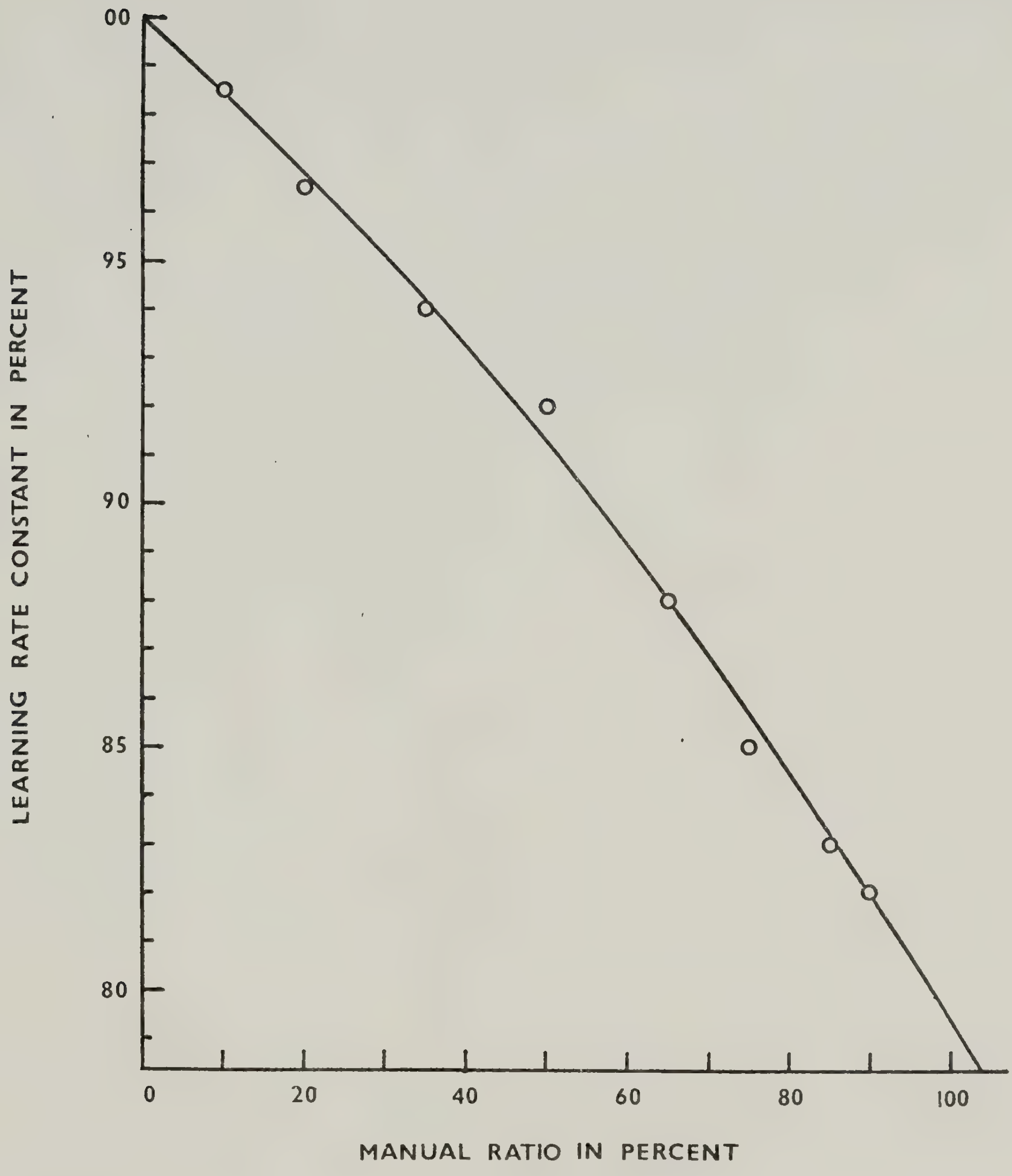

Figure A4.1. Correlation Curve for the Learning Rate Constants